AN ANALYSIS OF THE RADIOLOGICAL PARAMETERS THAT MAY INFLUENCE THE DEVELOPMENT AND PROGRESSION OF ADULT ISTHMIC SPONDYLOLISTHESIS AT L5- S1 LEVEL WITH A CRITICAL ANALYSIS OF THE ROLE OF PELVIC INCIDENCE.

A DISSERTATION SUBMITTED TO THE TAMIL NADU DR M.G.R MEDICAL UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF M.S. (ORTHOPAEDIC SURGERY) BRANCH II DEGREE MARCH 2011-2013

CERTIFICATE

This is to certify that the dissertation titled**, "An analysis of the radiological parameters that may influence the development and progression of adult isthmic spondylolisthesis at L5 – S1 level with a critical analysis of the role of pelvic incidence"** is the bona fide work done by **Dr Sanju Daniel**, in the Department of Orthopaedics, Christian Medical College Vellore, in partial fulfilment of the requirement of the Tamil Nadu Dr. M.G.R Medical University, for the award of M.S. Degree Branch II (Orthopaedic Surgery) under the supervision and guidance of Prof. Dr. Kenny S David during the period of his post graduate study from March 2011 to February 2013.

This consolidated report presented herein is based on bona fide cases studied by the candidate himself.

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ACKNOWEDGEMENTS

I would like to acknowledge a few people who have been of great help in preparing this manuscript.

First of all , I'd like to thank my guide, Dr Kenny S David for all the guidance and support he gave me from the beginning of my M.S course . I thank him for the patience and sacrifice he took to teach me.

I thank all the other faculty in the department who have been very supportive throughout this teaching program.

I thank all my colleagues , staff and patients of CMC hospital for their co-operation and support in making this thesis

I thank Dr John George and Dr Sherry Verghese, two people who are role models, as orthopaedic surgeons and good citizens, to me.

I thank my wife Dr Seethu, my son David, and my sister Dr Manju for being there for me always. I thank my parents for all their support , guidance. I am grateful for their various sacrifices for my better future.

Above all, I thank God almighty for the numerous blessings he has showered upon me throughout my life.


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INTRODUCTION

Spondylolisthesis is a condition which is unique to humans and has not been reported in animals. This is possible due to the bipedal gait of mankind and the lumbar lordosis. The human spine is a multilinked system of various curves in the sagittal plane. There are thoracic and pelvic kyphoses to begin with. The cervical lordosis appears as the infant rolls over and sits up. The lumbar lordosis appears last as the infant begins to stand and walk at about eighteen months. The lumbar lordosis, thoracic kyphosis cervical lordosis function in unison to provide an energy efficient system that maintains posture of the organism. Any challenge to this harmony can lead to stress and strain at various levels.

Spondylolisthesis is a condition in which one vertebra slips over the adjacent vertebra in the sagittal plane. The condition was first described as cause for obstructed labour by Belgian obstetrician Herbinaux in the year 1782(1). Later it has been the subject of study of many scholars. Although much has been gained from these studies many of the questions are still unanswered and hence the topic is one of continuing research. The erect spine is pre-requisite for this pathology and it is not found in non ambulatory population. The prevalence of spondylolisthesis in general population is variedly reported by different investigators, but is reported to be around six percent.

Of the five main types, the isthmic variety is the most extensively studied. The influence of the pelvic anatomy on the development and progression of isthmic spondylolisthesis has been an area of debate in the recent past. The aim of this study is to throw some light on the association of spino-pelvic radiological parameters with spondylolisthesis.

REVIEW OF LITERATURE

A. HISTORICAL BACKGROUND

The condition of spondylolisthesis was first described in 1782 by Herbinaux, a Belgian obstetrician who found unusual difficulty in a labour with pelvic outlet obstruction. He termed the condition as a lumbosacral dislocation. The term spondylolisthesis was later coined by Killian(2). The literal meaning has two parts, spondylo means spine, and listhesis means to slip over the slippery path(2) . Spondylolysis refers to a defect in the pars interarticularis without slippage of the vertebra. Lysis means dissolution. It is also called spondyloschisis. Schisis means cleavage. Junghans and later Macnab coined the term Pseudospondylolisthesis for forward slipping of the entire vertebra due to wearing of cartilage of the articular processes without true pathology of the pars(3).

B. RELEVANT ANATOMY

The adult human vertebral column consists of thirty three vertebrae. There are usually seven cervical, twelve thoracic, five lumbar, five sacral and five coccygeal vertebrae. These numbers are subject to frequent variability and many a time reports of thirty two and thirty five vertebrae are documented(4). These vertebrae are stacked one over the other with intervening intervertebral discs. The sacral and coccygeal vertebrae are usually fused to form two functional units. The morphology of the vertebra at different levels is quite peculiar to that level although this demarcation based on morphology may be blurred(4). The fifth lumbar vertebra may show features of sacral vertebra and vice versa.

Embryologically, the vertebra are intersegmental, forming from the fusion of the caudal part of one sclerotome and the cranial aspect of the next sclerotome. The intervertebral disc is segmental , arising from a single sclerotome(5). Each vertebra is formed from three centres of ossification, one for each side of the neural arch and one for the body.(5) At birth, the ossification centres of the neural arches fuse with each other. Failure of this fusion results in spina bifida.

The normal lumbar vertebra may be considered as two parts, an anterior portion and a posterior portion. The anterior portion consists of the body of the vertebra, which is essentially a block of cancellous bone surrounded by a shell of cortical bone. The body has important haemopoietic functions and protects the spinal cord from anterior aspect. From the posterolateral aspect of the body arise two tubular cortical bony structures one on each side, called the pedicles. The posterior aspects of the pedicles expand to form the lamina. The laminae join each other medially to complete the neural arch. From the posterior aspect of their junction arises the spinous process. The transverse process arises from the posterolateral aspect of this neural arch. From the junction of pedicle and lamina superiorly is the superior articular process. Inferiorly, there arises the inferior articular process.

The pars interarticularis is a thin bicortical region of the posterior arch where the lamina and inferior articular process intersect with the pedicle and superior articular process(6). The pars interarticularis is the point of pathology in isthmic spondylolisthesis. The defect in the pars is referred to as spondylolysis. The defect may be unilateral or bilateral. Unilateral spondylolysis does not cause slippage(6). Bilateral weakness in the pars causes separation of the posterior part of the neural arch from the rest of the vertebral body resulting in slippage of the cranial vertebral segment over the caudal segment. Each half of the neural arch arises from a separate ossific center, and the failure of fusion of these two centres has been postulated to result in the defect of the pars interarticularis. This theory has however never been proven.

In the human spine the vertebra form a smooth multi linkage system, with its various curves. The head is balanced on the cervical spine which articulates with the torso which articulates with the pelvis which in turn articulates with the lower limbs through the hips(7). This system is normally highly energy efficient in maintaining a stable posture with minimum expenditure of energy and muscle strain.

The adult human spine exhibits four normal curves in the sagittal plane, viz a cervical lordosis, thoracic kyphosis, lumbar lordosis, pelvic kyphotic curvature. The embryo has a grossly flexed posture and only has thoracic and pelvic curves which are convex dorsally(4). Hence the thoracic and pelvic kyphoses are called the primary curvatures. The cervical and lumbar curvatures appear secondary to functional muscle development. The neonate vertebral column has no fixed curvatures(4). At about three to five months, the infant is able to hold the head up, and this is when the cervical lordosis appears. At about twelve to fifteen months the infant begins to stand and start walking , and this is when the lumbar lordosis appears. The secondary lumbar curvature is very important in maintaining the centre of gravity of the trunk over the lower limbs(4).

In adults the cervical lordosis extends from first cervical vertebra to the second thoracic vertebra with it apex at the fourth cervical vertebra. The thoracic kyphosis extends from second thoracic vertebra to the twelfth thoracic vertebra with its apex between the sixth and ninth vertebra. The thoracic kyphosis is due to the increased posterior height of the thoracic vertebral bodies(4). The lumbar lordosis extends from first lumbar vertebra to the lumbo- sacral junction. The greater anterior height of the intervertebral discs and some posterior wedging of the vertebral bodies contribute to the lumbar lordosis(4) . The lumbar lordosis is more pronounced in females. The pelvic curve is again convex dorsally and extends from lumbosacral junction to the tip of the coccyx.

There are no lateral curves in the spine. Occasionally a slight lateral curve with convexity to right in right handed people and convexity to left in left handed people may be found in the thoracic spine(4). The sagittal curves of the human spine have developed as a result of the unique bipedal gait of mankind. This same unique adaptation has led to unique problems in the spine of human beings , as spondylolisthesis and intervertebral disc prolapse have not been described in lesser animals including members of the primate family(8).

C. PREVALENCE OF SPONDYLOLYSIS AND SPONDYLOLISTHESIS

The prevalence of spondylolysis in general population has been variously reported by many authors, but is considered to be around 6% . One of the landmark studies was a cross sectional study of five hundred first grade children who were examined with roentgenograms .The incidence of spondylolysis in them was 4.4 %(6). The same cohort was followed up with X-rays at twelve years, sixteen years and at adult hood. The incidence was recorded as 5.2, 5.6 and 6 percent respectively. Spondylolysis may occur unilaterally. Unilateral spondylolysis does not cause spondylolisthesis. The incidence of slip in bilateral spondylolysis is 50-75%(6).

In a recent study, the abdominal and pelvic CT scans of five hundred and ten patients taken for various reasons like fever, abdominal pain and unrelated symptoms was studied to detect the prevalence of spondylolysis and spondylolisthesis. The authors concluded that the prevalence of spondylolysis was 5.7 % and that of spondylolisthesis was 3.1 %(9).

Spondylolysis is not seen at birth(10). The erect spine is a pre-requisite for spondylolysis to occur. The condition is also not seen in non ambulators. The pars defect is said to occur in between the ages of five and half to seven years(11). Slippage occurs and progresses in teenage and is maximum between ten and fifteen years(11). Borkow and Kliegen(12) have reported the case of a neonate with muliple level spondylolysis in the thoracic and lumbar spine. This is a possible exception to the stated rule of spondylolysis being not seen in newborn. However, it is likely that this was secondary to some bone dysplasia.

The classical teaching that spondylolisthesis does not occur in non- ambulators was challenged when the case of seventeen year old girl with cerebral palsy girl who was non ambulatory since birth was reported(13). The girl was incidentally found to have spondylolisthesis when X-ray was taken for some hip symptoms. The cause in this case was presumed to be due to disuse osteopenia combined with the excessive lumbar lordosis due to the hip flexion contracture.

It has been conventionally taught that that slippage may progress upto the age of twenty, after which further slippage does not occur(11). This may not hold true as there are reports in recent literature about adult onset slip progression. It is a distinct clinical entity that causes axial back pain and leg pain. This slip progresses as the L5- S1 disc loses its structural and functional integrity. Adult slip progression is stated to occur in about fifteen percent of adults with spondylolisthesis after the age of thirty(14). What exactly causes the slippage to progress in some patients and not in others is still an enigma.

The prevalence of spondylolysis is more common in males , but progression of the spondyloysis or spondylolisthesis is more common in females(15) . This may be due to the more laxity of tissue and the increased lumbar lordosis seen in women. Studies on the progression of the spondylolisthesis in pregnancy have shown that there is no difference between the degree of slip after and before pregnancy. This is also surprising since pregnancy is a condition of increased lumbar lordosis and ligamentous laxity.

The prevalence of spondylolysis and spondylolisthesis has been consistently shown to be higher in certain populations. The prevalence of the condition in Alaskans is forty percent and that in Eskimos is fifty four percent(16). This could be due to the genetic predisposition or the similar physically intensive lifestyle of both populations.

The incidence of spondylolysis has been shown to be higher in conditions producing hyperlordosis. Scheuermann's disease is one example where there is increased incidence of spondylolysis due to the lumbar hyperlordosis(17) . Here the lumbar hyperlordosis develops to compensate for the thoracic hyperkyphosis. Hyperlordosis can also be secondary to any pathology causing fixed flexion deformity at the hip joints. Hyperlordosis is also commonly found in ballet dancers.

D. ETIOLOGY.

The etiology of spondylolisthesis may be multifactorial. Spondylolisthesis should be considered to be the common radiological result of different and distinct disease processes.(18) In 1976 , a classification based on the etiology was described by Newman, Macnab, and Wiltse(19). It was further modified by Marcheti and Bartolozi in 1997 (20) . The Newman – Wiltse classification divides spondylolisthesis into five types based on the etiology.

I Dysplastic

II Isthmic

III Degenerative

IV Traumatic

V Pathological

The isthmic variety is the most common and most widely studied among the others, to such an extent that spondylolisthesis if not otherwise mentioned means isthmic spondylolisthesis.

I. Dysplatic spondylolisthesis:

This is perhaps what Junghans and Macnab(3) had earlier described "pseudospondylolisthesis". In this variety which may be found in birth there is gross dysplasia of the inferior articular process of L5 and the superior articular process of S1. As a result there is slippage of L5 over S1 in the presence of a normal pars interarticularis.

II. Isthmic Spondylolisthesis:

This is the most common type and the most researched one. In this , there is true spondylolysis with defect in the pars interarticularis. According to the American Academy of Orthopaedic Surgeons glossary on terminology of spinal disorders, 'Isthmic spondylolisthesis is described as a condition in which fibrous defects are present in the pars interarticularis which permit forward displacement of the upper vertebrae and separation of the anterior aspects of the vertebra from its neural arch'

The isthmic variety of spondylolisthesis has been further classified into three types:

II A - The defect is secondary to a fatigue fracture of the pars.

II B – The pars is intact but elongated

III C- There is an acute fracture of the pars.

The etiopathogenesis of the isthmic variety of spondylolisthesis has been extensively studied by many authors, including Wiltse who in his lecture on the eiology of spondylolisthesis(10) elucidated multiple theories. The various theories presented by Wiltse are as follows

-The lateral mass ossifies by two centres in spondylolisthesis.

- The defect in the neural arch is a birth fracture.

- The defect in the neural arch is a post-natal fracture that has failed to heal.

-The defect in the neural arch is a stress fracture.

- Increasing lumbar lordosis causes defects in the pars interarticularis

- The defect in the neural arch is due to impingement of the articular processes on the pars interarticularis.

- The defect is due to deficient supporting structures.

-Weakness of the pars is caused by pathological changes like aseptic necrosis.

- The defect in the neural arch is due to dysplasia of the pars

It has been postulated that each side of the neural arch develops from two separate ossific centres, one superior and one inferior. The pars defect arouse as a result of the failure of their fusion. Extensive cadaveric study and radiographic analysis have failed to demonstrate the presence of such ossific centres.

The suggestion that the pars was a birth fracture was disproved by Rowe and Roche(21)in 1953 as they could not produce a pars fracture in stillborn infants. Another theory that is popular is that the pars defect is a fracture in postnatal life. The fact that pars defect is not found at birth supports this theory. The lysis is supposed to be a fracture that does not heal. Many of the cadaveric and radiological studies have demonstrated that there is no evidence of any attempt of healing in the pars defect which challenges this theory.

Roberts, in 1947,(22) put forward the idea that the spondylolysis was a stress fracture of the pars interarticularis. This was further supported by other authors like De Palma in 1959 (23) who demonstrated pars defect developing in lumbar vertebra after fusion of adjacent vertebrae. Any increase in lumbar lordosis can cause increased shear forces across the lumbosacral junction. This may precipitate the development of a defect in genetically weakened pars. Stewart in 1956 after multiple cadaveric studies in Eskimos found that the unusually higher rate of spondylolysis may be due to the increased lumbar lordosis(24). The sacral end plates of the cadavers he studied were almost vertical.

Nath Hilel in 1959 postulated that the pars defect was due to the pars interarticularis being impinged between the superior and inferior articular processes of the superior and inferior adjacent vertebra respectively(25). He made his conclusions after dissecting nineteen skeletons with spondylolysis. He called the phenomenon as the ‘pincer effect’. He also described the role of trauma, age, sex, race, heavy labour, as other adjuvant precipitating factors.

In 2006, Rosssouly et al described a similar theory for the etiology of isthmic spondylolisthesis. According to him, the biomechanical cause of the pars defect is either ‘Traction or Impingement’(26). In high pelvic incidence pelvices, the higher stress across the lumbosacral junction exerts increased traction on the L5 pars interarticularis. In low pelvic incidence, the pars defect is due to impingement between the L4 and S1 articular processes. Here the pelvic incidence describes the relationship of the plane of the sacral end plate to the axis of rotation of the femoral heads(27).

Newman in 1955 had postulated a theory that spondylolysis occurred in a normal pars secondary to instability due to weakened supporting structures like the lumboscral fascia, intervertebral disc, and posterior longitudinal ligaments(28) . Wiltse contended that lysis is seen in children with no evidence of weakness of supporting structures. Moreover patients with poliomyelitis having weakness of back muscles have no sign of spondylollysis.

In 1956 , Neugebauer (29) in his article had published the theory that the pars defect was a dysplasia of the pars.

The genetic predisposition of isthmic spondylolisthsesis has been well investigated by many authors. In 1950 , Wiltse(8) chose a cohort of 101 people from thirty six families . He detected that 26% of the hundred and one had evidence of lysis. Wiltse thought that this could not be sheer coincidence. In 2003, the Cartilage Derived Morphogenetic Protein1, (CDMP1) was found to be mutated in individuals with spondylolysis(30). Hence mutations in these genes were suggested to be an etiology for spondylolysis. CDMP1 genes are essential in the normal chondrogenesis patterns of vertebrae. Their mutations cause abnormalities in the endplate morphology of vertebrae. The case for genetic cause was further strengthened when in 2011, Leiven Moke etal published the case report of two twins with spondylolisthesis(31). The twins did not have CDMP1 mutations, although it cannot be disproved as a etiology.

III. Degenerative Spondylolisthesis

In this type of spondylolisthesis, the slip occurs due to the degenerative changes in the facet joints and the intervertebral discs. This type of spondylolisthesis is most common at L4-L5 level. Here, the central spinal canal is narrowed progressively as the slip progresses unlike the isthmic type where there is increase in anteroposterior diameter of the canal as the slip progresses. Hence neurologic claudication and radiculopathy appear early in degenerative spondylolisthesis.

IV. Traumatic Spondylolisthesis

This type of spondylolisthesis occurs following trauma with dislocation of the facet joints. It can occur at any level but particularly more around the thoracolumbar junction.

V. Pathological Spondylolisthesis

This type of spondylolisthesis occurs secondary to pathological conditions of the bone like tumour, Paget’s disease, and other bone softening condition.

E. PATHOLOGY

The pars defect tissue has been studied in cadaveric dissection by various authors. Four different types of tissue have been described(32).

1. Thin fibrous bands bridging the defect in the pars interarticularis.

2 .Thick heavy fibrous columns bridging the defect in the pars

3. Bony bridge across the portion of the pars where the defect had been suspected

4. False joint in the region of the pars.

F. CLASSIFICATIONS.

The initial classification was by Wiltse, Newman and Macnab according to the etiology of spondylolisthesis(19). This classification has been discussed in detail above. The Wilse, Newman, Macnab classification was further modified by Marchetti and Bartolozi in 1997(20). According to this classification, there are two main categories, which are developmental and acquired. The dysplastic and isthmic varieties of Wiltse- Newman classification have been clubbed to form the developmental group and the rest three varieties are included in the acquired group.

1) MARCHETTI AND BARTOLOZI CLASSIFICATION(20)

A) Developmental types

I High dysplastic

With lysis

With elongation

II Low dysplastic

With lysis

With elongation

B) Acqiured types.

I Traumatic

Acute fracture

Stress fracture

II Post Surgery

Direct surgery

Indirect surgery

III Pathological

Local pathology

Systemic pathology

IV Degenerative

Primary

Secondary

In 2005 Herman and Pizutillo suggested a new classification system spondylolisthesis in the child and adolescent(33). Their classification is important in the sense that spondylolisthesis or spondylolysis is the most common organic cause of back pain in pediatric age(34). The authors felt that although the literature is extensive, there were many confusions and imprecisions regarding the etiology, terminology, subtypes, treatment protocols based on the existing classifications. Hence they introduced the new classification.

Herman and Pizutillo classification.

I Dysplastic

II Developmental

III Traumatic

A. Acute

B. Chronic

Stress reaction

Stress fracture

Spondylolytic defect (non union pars)

IV Pathological

Intraosseous oedema with surrounding sclerosis of the pars, lamina, or pedicle without cortical or trabecular disruption is termed a stress reaction. Disruption of trabecular or cortical bone of the pars without a bony gap or lysis is termed a stress fracture. Complete disruption of the pars interarticularis with a gap and surrounding sclerosis at the edges of the defect is defined as a spondylolytic defect or nonunion of the pars(33).These findings are obtained from computed axial tomography of the region.

The type I or dysplastic type is the same as the dysplastic type in Newman- Wiltse classification(19). They represent the spondylolisthesis which have no abnormality of the pars and are due to the failure of normal development of posterior elements of the spine. This category of patients have increased chance of progression unlike the isthmic variety . Chances of progressive deformity with neurological involvement, radiculopathy, bladder involvement is higher, hence close observation is needed for these patients.

Type II, the developmental type in this classification refers to the child or adolescent who presents with an incidentally detected defect of the pars. CT evaluation shows the defect to be trabecular disruption with surrounding sclerosis. These patient have less chance of progression or severe deformity. It is in this type that genetic susceptibility is described with a 26 percent incidence in first degree relatives(35).

Type III refers to the traumatic type of spondylolysis or spondylolisthesis. Type IIIA, acute traumatic spondylolysis and spondylolisthesis, is an acute fracture of the pars, the lamina, or the pedicle that results from high-energy trauma such as a motor vehicle accident. This subtype is uncommon in paediatric age and the treatment depends on the neurological status and degree of instability.

Type IIIB, chronic traumatic spondylolysis and spondylolisthesis, refers to those patients who present with chronic or intermittent back pain and a history of participation in a sport or activity that involves repetitive loading of the lumbar spine. Imaging of the lumbosacral spine may reveal an obvious non-union of a pars defect, termed a Type IIIB spondylolytic defect, or spondylolisthesis with pars discontinuity, termed Type IIIB spondylolisthesis. If the CT cuts show intact trabeculae with surrounding sclerosis ,it is called stress reaction . If the CT cut shows disruption of the bony pars with no sclerosis, it is considered a stress fracture.

The type IV or pathological type is seen secondary to pathological conditions of the pars, lamina, or the pedicles due to neoplasm, osteogenesis imperfecta etc.

It is noteworthy that the degenerative type of spondylolisthesis of the Newman-Wiltse classification is missing as this is a system for the pediatric population.

Table1 . showing the various classifications for spodylolisthesis, including the newer system for pediatric subjects (33)

(Taken from -Martin J. Herman, MD; and Peter D. Pizzutillo, MD Spondylolysis and Spondylolisthesis in the Child and Adolescent A New Classification CORR Number 434, pp. 46–54)

WILTSE-NEWMAN	MARCHETTI-BARTOLOZZI	NEW CLASSIFICATION
I. Dysplastic	**Developmental**	**I. Dysplastic**
II. Isthmic	High dysplastic	**II. Developmental**
A. Lytic-fatigue fracture of pars	With lysis	**III. Traumatic**
B. Elongated but intact pars	With elongation	A. Acute
C. Acute pars fracture	Low dysplastic	B. Chronic
III. Degenerative	With lysis	-stress reaction
IV. Traumatic	With elongation	-stress fracture
V. Pathologic	**Acquired**	-spondylolytic defect
	Traumatic	(nonunion of pars)
	Acute fracture	**IV. Pathologic**
	Stress fracture	
	Post-surgery	
	Direct surgery	
	Indirect surgery	
	Pathologic	
	Local pathology	
	Systemic pathology	
	Degenerative	
	Primary	
	Secondary	

SPINAL DEFORMITY STUDY GROUP CLASSIFICATION(36)

The Spinal Deformity Study Group (SDSG) has introduced a new classification based on the slip grade, pelvic incidence, sacropelvic and spinal balance. This is based on the many recent reports that emphasise the role of sacropelvic morphology and spinopelvic alignment. Currently the SDSG classification lists six types of lumbosacral spondylolisthesis; three types for low grade slips and three types for high grade slips(36).

LOW GRADE

Type 1: Low Pelvic incidence , less than 45 degrees

(Nutcracker type)

Type 2: Normal pelvic incidence, between 45 and 60 degrees

Type 3 : High pelvic incidence, above 60 degrees

HIGH GRADE

Type 4 Balanced : With high sacral slope and low Pelvic tilt.

Type 5 Unbalanced Sacropelvic , Balanced spine: With low sacral slope and high pelvic tilt. C7 plumb line withhin hip axis.

Type 6 Unbalanced sacropelvis , Unbalanced spine: Low sacral slope, high . pelvic tilt. C7 plumb line in front of hip axis

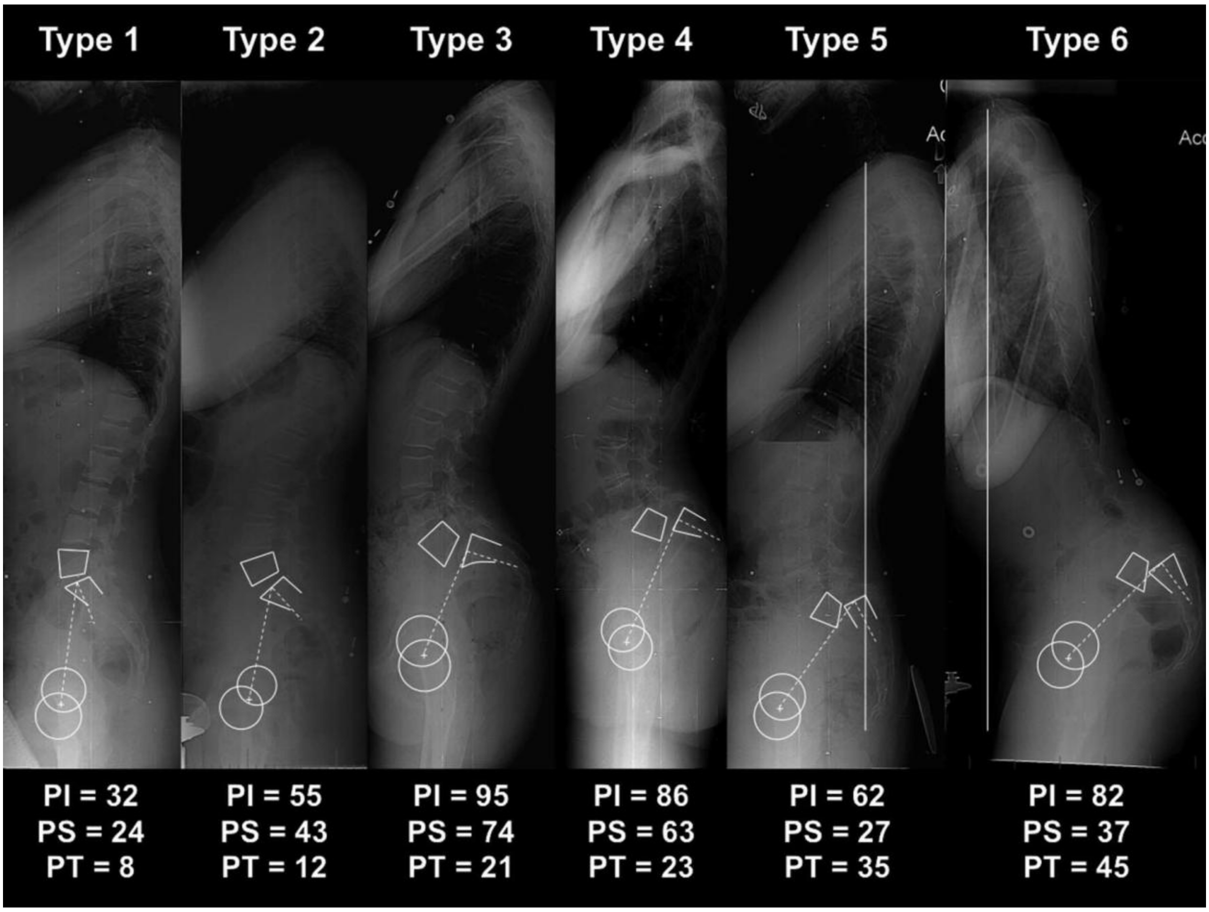


Figure 1. showing the Xrays of various classes of spondylolisthesis according to the SDSG classification. (36)

(Taken from -Jean-Marc Mac-Thiong Et al Reliability of the Spinal Deformity Study Group Classification of Lumbosacral Spondylolisthesis. SPINE Volume 37, Number 2, pp E95–E102.)

The concept of balanced and unbalanced sacropelvis in high grade spondylolisthesis was derived from the work of Hresko et al (37). The pelvis with the low sacral slope and high pelvic tilt are considered retroverted and modified reduction technique may be used for surgery in such cases. Spinal balance refers to the position of the C7 plumbline dropped from the center of the C7 vertebral body with respect to the hip axis (midpoint of the line joining the center of the 2 femoral heads). The spine is considered balanced when the C7 plumbline falls at or behind the hip axis, whereas it is unbalanced when it is in front of the hip axis. The hip axis is formed by a horizontal line connecting the centre of the femoral heads.

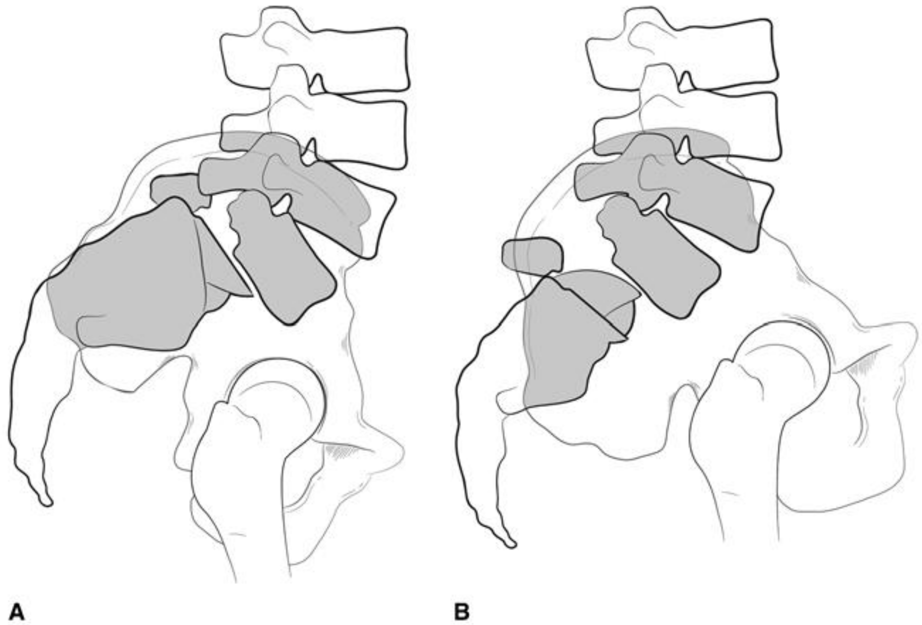


Figure 2. Showing A- Balanced pelvis with high grade spondylolisthesis.

B Unbalanced Pelvis with retroversion and high grade spondylolisthesis.

(from Michael T. Hresko, et al Classification of High-Grade Spondylolistheses Based on Pelvic Version and Spine Balance SPINE Volume 32, Number 20, pp 2208–2213)

G CLINICAL PRESENTATION.

The prevalence of low back pain in people with spondylolysis is similar to that in general population(34). The most common presentation is asymptomatic, incidentally detected. The presentation of pain in spondylolisthesis is usually insidious onset gradually progressive low back pain that occasionally radiates to the buttock or posterior thigh, radicular pain with bowel or bladder involvement is rare in spondylolysis . Acute onset back pain may be found in athletic gymnastic populations, in whom there is a higher incidence of spondylolysis.

In a person with spondylolysis presenting with back pain, it is important to rule out other organic causes of back pain like disc herniation, lumbosacral strain and sprain and neoplasm. The presence of rest pain and night pain points toward inflammatory or neoplastic etiology. To confirm whether the pars defect is the source of pain, Single photon emission computed tomography (SPECT) may be done. A negative SPECT in the presence of a defect suggests that it is not the source of pain(33). The causes of axial back pain in spondylolisthesis include referred pain from degenerative disk, facet joint, as well as from increased stress on the annulus fibroses at the slip level(38). Disc degeneration also causes back pain.

The clinical course of patients with dysplastic type of spondylolisthesis is more aggressive. They tend to have increased frequency of back pain with radiculopathy, lumbar canal stenosis, cauda equina involvement. In dysplastic type of slip, the whole vertebra with anterior and posterior elements slips over the caudal vertebra resulting in narrowing of the central spinal canal and foramina. In isthmic spondylolisthesis this does not occur unless in high grade slip(39).

The range of motion of the spine is usually normal, but there may be a painful limitation of extension of the spine. It is imperative do a thorough neurological assesement including the bowel and bladder and deep tendon reflexes. The nerve tension signs are usually negative unless in sever slip with nerve root irritation.

H IMAGING

Frank spondylolisthesis is well visualised on the plane lateral X-ray. The standing X-ray is required to load the spine and reveal any occult spondylolisthesis of the spine. Bilateral defects of the pars are also easily visualised on the lateral lumbosacral spine. Unilateral defects are seen on the oblique view appearing as the 'collar of the Scotty dog'(40).

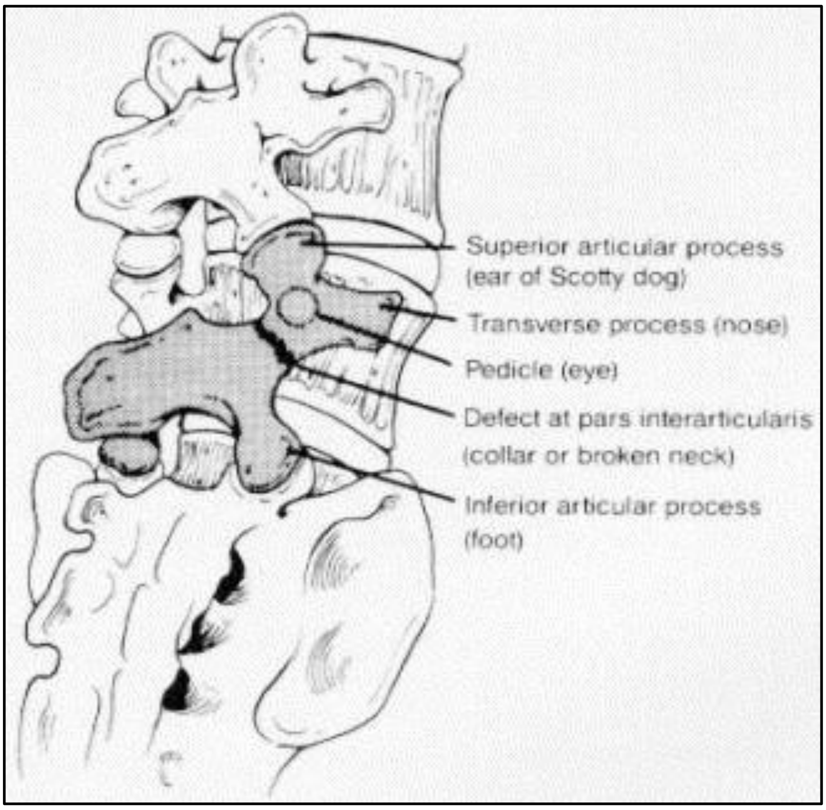


Figure 3. showing anatomic land marks representing 'The Scotty Dog Sign' .

(Taken from Orthopedic Clinics of North America Volume 30, Issue 3, 1 July 1999, Pages 487–499).

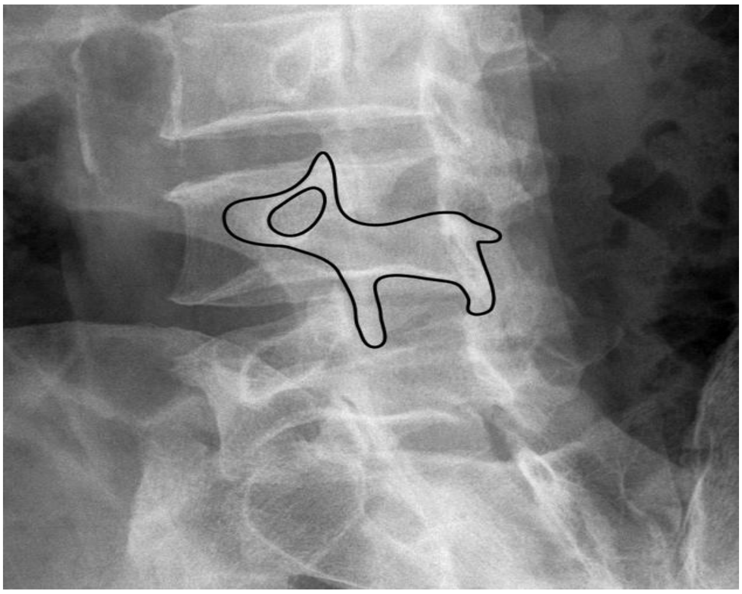


Figure 4. showing 'The Scotty Dog' in the oblique lumbar spine X-ray. (Taken from Radiology Articles Section Signs, radiopaedia.org).

Figure 5. showing ''Collar Of The Scotty Dog' representing the pars interarticularis defect. .(Taken from Radiology Articles Section Signs, radiopaedia.org)

The contra lateral intact pars may be seen as sclerotic in the oblique view. 'Grey hound sign' is used to describe the intact but elongated pars (41). Here the pars appear as the gracile neck of a grey hound. Recently CT has been described to be a sensitive test to detect occult lysis . A study done using CT imaging demonstrated that the prevalence of spondylolysis may be double the number previously recorded(9).

In the anteroposterior Xray, sagittal deformity may be suggested by the presence of an 'Inverted Napoleon's hat' sign at the level of L5 and the sacrum. The sign is visible when a superimposed axial view demonstrates the L5 vertebral body overlying the sacrum.

Figure 6. showing the photograph of the 'Napoleon hat'.

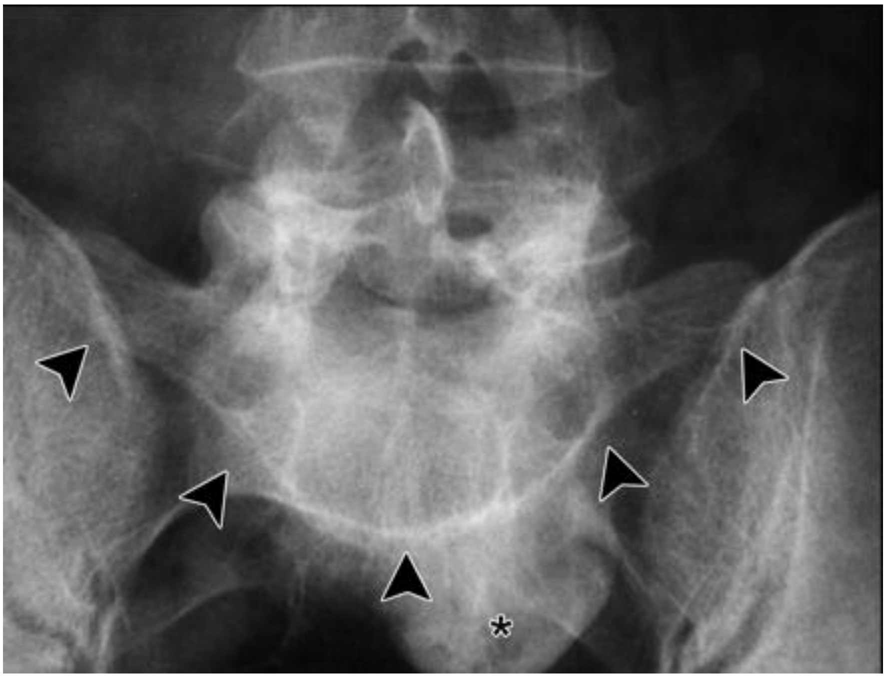


Figure 7. showing the ‘Inverted Napoleon hat sign’ in the anteroposterior view of lumbosacral spine with high grade spondylolisthesis.

(Taken from Leizle E. Talangbayan, The ‘Inverted Napoleon's Hat Sign. May 2007 Radiology, 243, 603-604.)

GRADING OF THE SPONDYLOLISTHESIS

Meyerding in 1932 described a simple method of grading the degree of slip (42). According to him , the superior sacral end plate is divided into four equal parts. However he did not mention the landmark to be used on the L5 end plate to assess the slip. Some authors subsequently described a line drawn from the poster-inferior corner of the L5 vertebral body and perpendicular to the sacral endplate using its intersection point with the sacral endplate

to quantify the position of L5 on S1 On the opposite, others used a line fitting the posterior wall of the vertebral body of L5 extrapolated onto the sacral endplate to achieve the same purpose(43). Three main modifications based on the Meyerding method exist to quantify the slip(27). They are as follows:

Taillard method:

Here the slip is expressed as a percentage of the distance between the posterior end of superior sacral end plate and posterior end of inferior L5 endplate(line A), to the total length of the superior sacral end plate (line B)

Boxall method:

Here the line A is same as above but the line B is total length of the inferior endplate of L5. The ratio between A and B is calculated as percentage.

Wright and Bell method:

Here the line A is same as before . The line B is the total length of the superior end plate of L5. Ratio of A/ B is calculated.

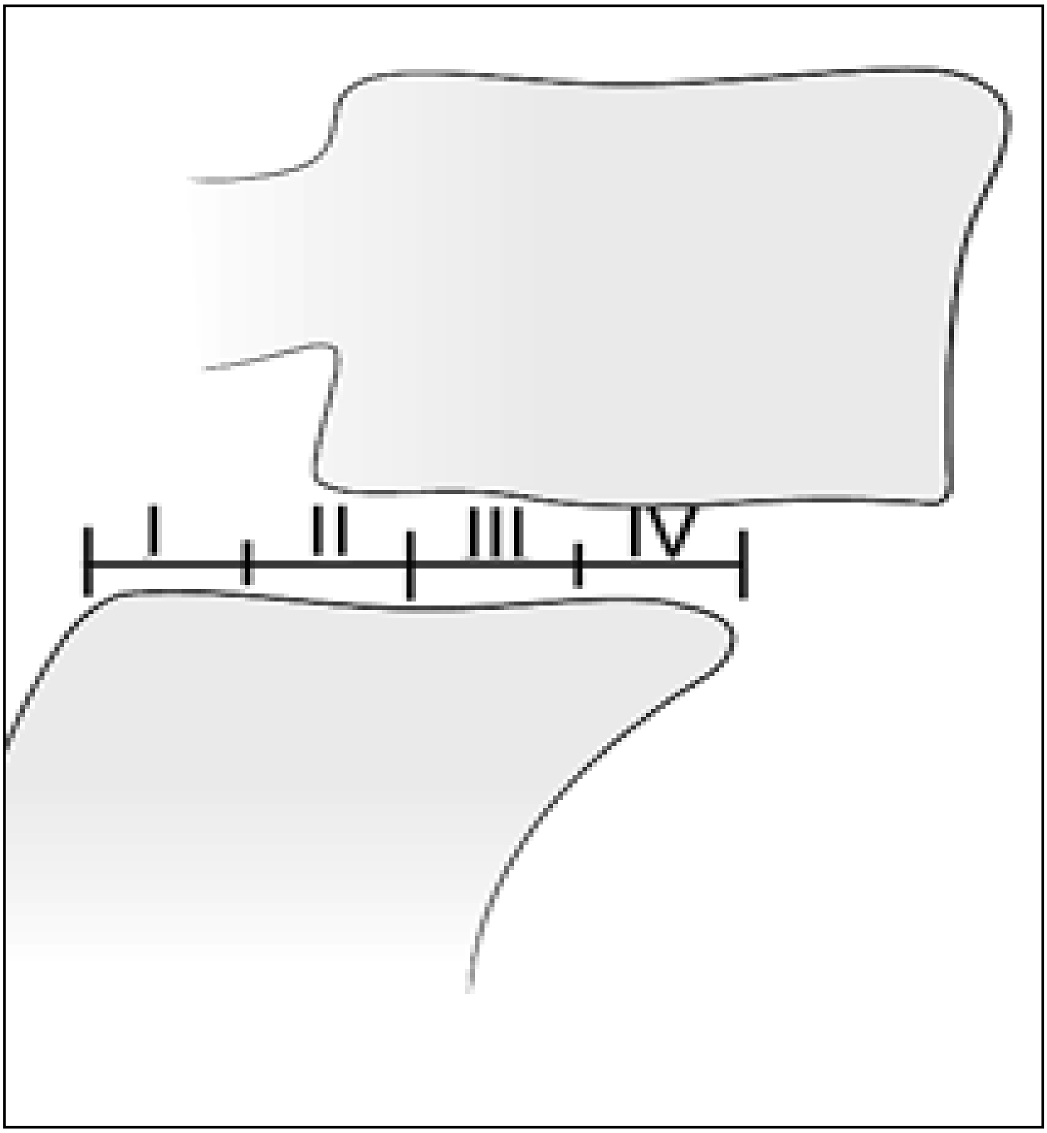


Figure 8. The Meyerding method of measuring the percent of slip by dividing the superior end plate of the sacrum into four quadrants.

(Taken from *J Am Acad Orthop Surg* 2012;20: Radiographic analysis of spondylolisthesis and sagittal spinopelvic deformity)

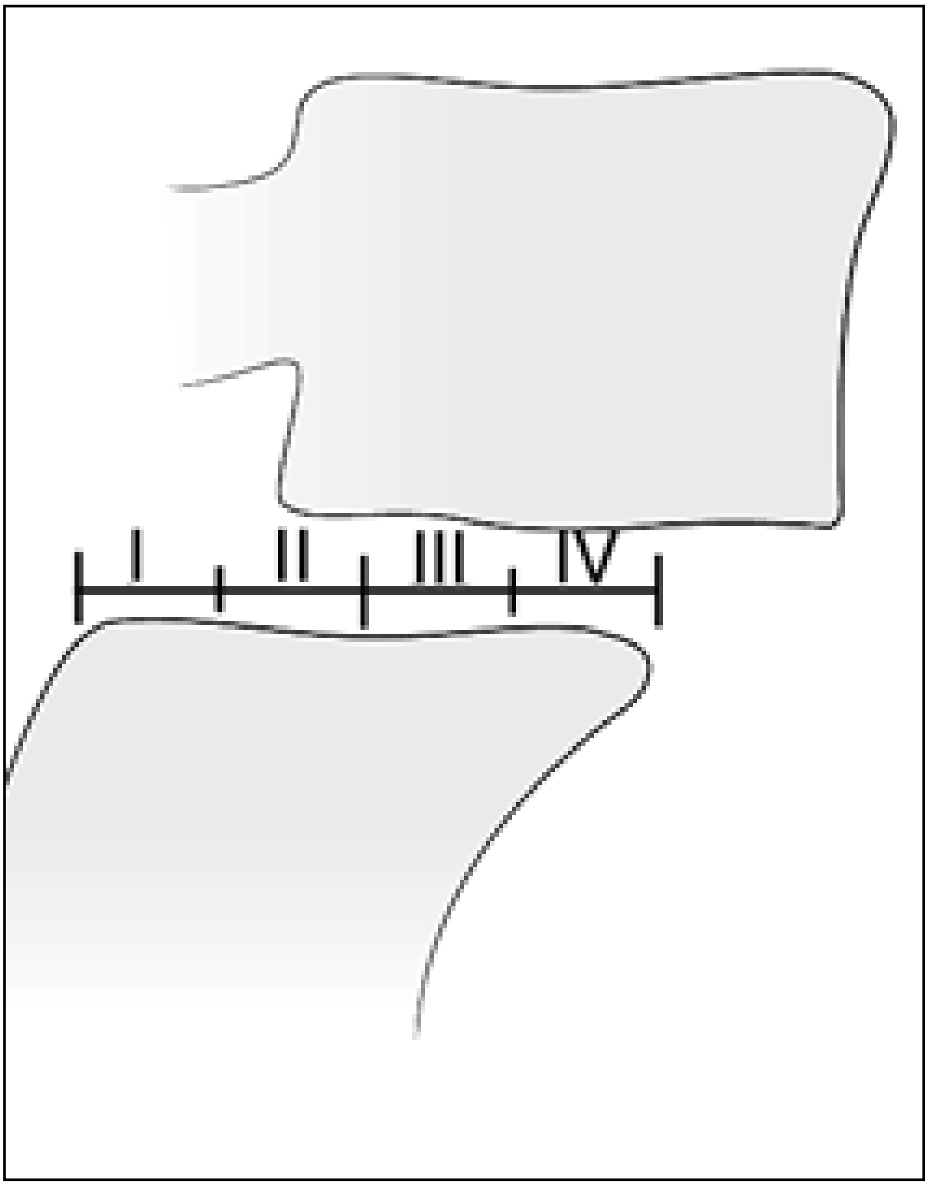


Figure 9. The measurement of the slip percentage by Taillard method

(Taken from *J Am Acad Orthop Surg* 2012;20: Radiographic analysis of spondylolisthesis and sagittal spinopelvic deformity)

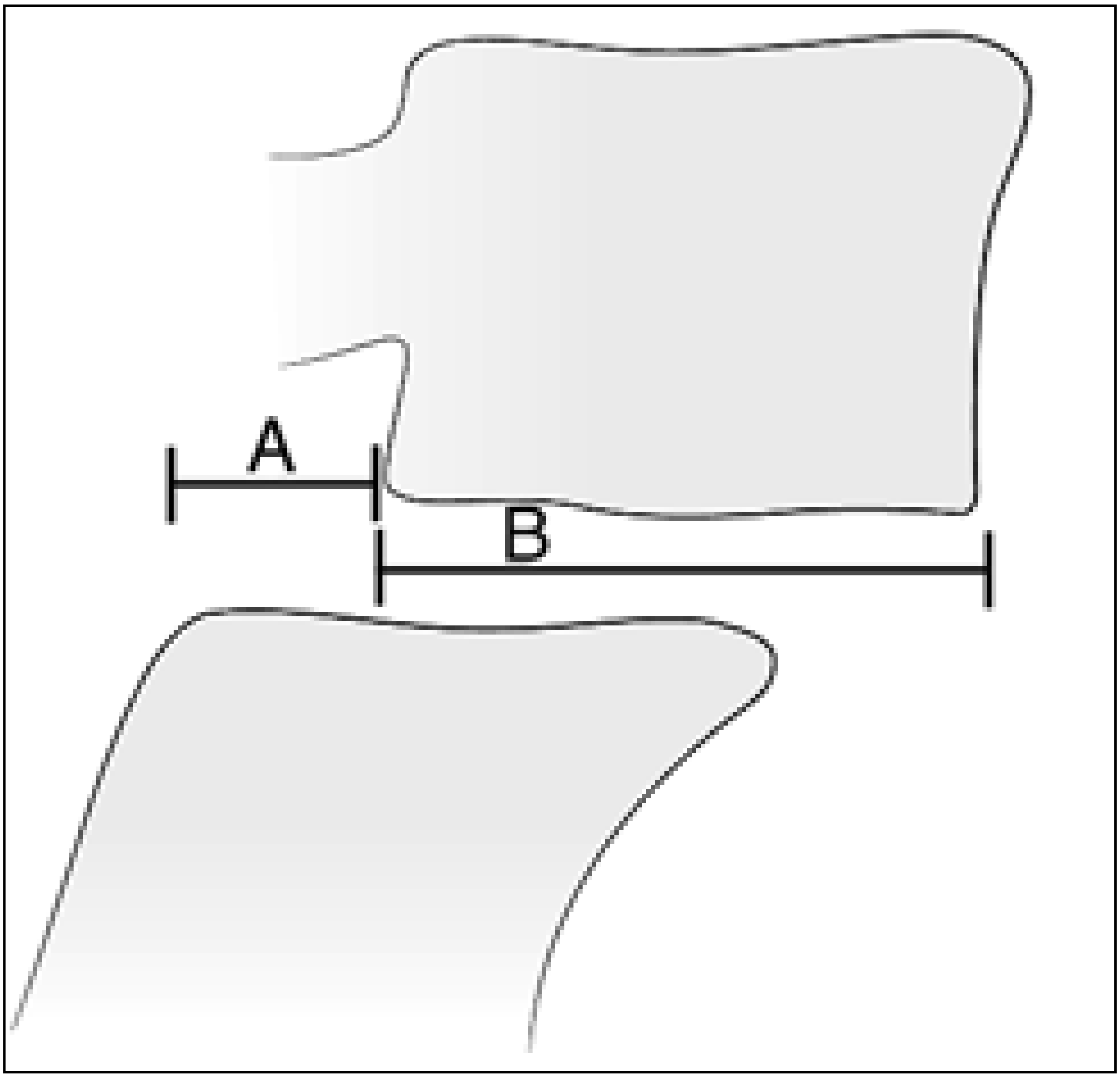


Figure 10.The measurement of the slip percentage by Boxall method.

(Taken from *J Am Acad Orthop Surg* 2012;20: Radiographic analysis of spondylolisthesis and sagittal spinopelvic deformity)

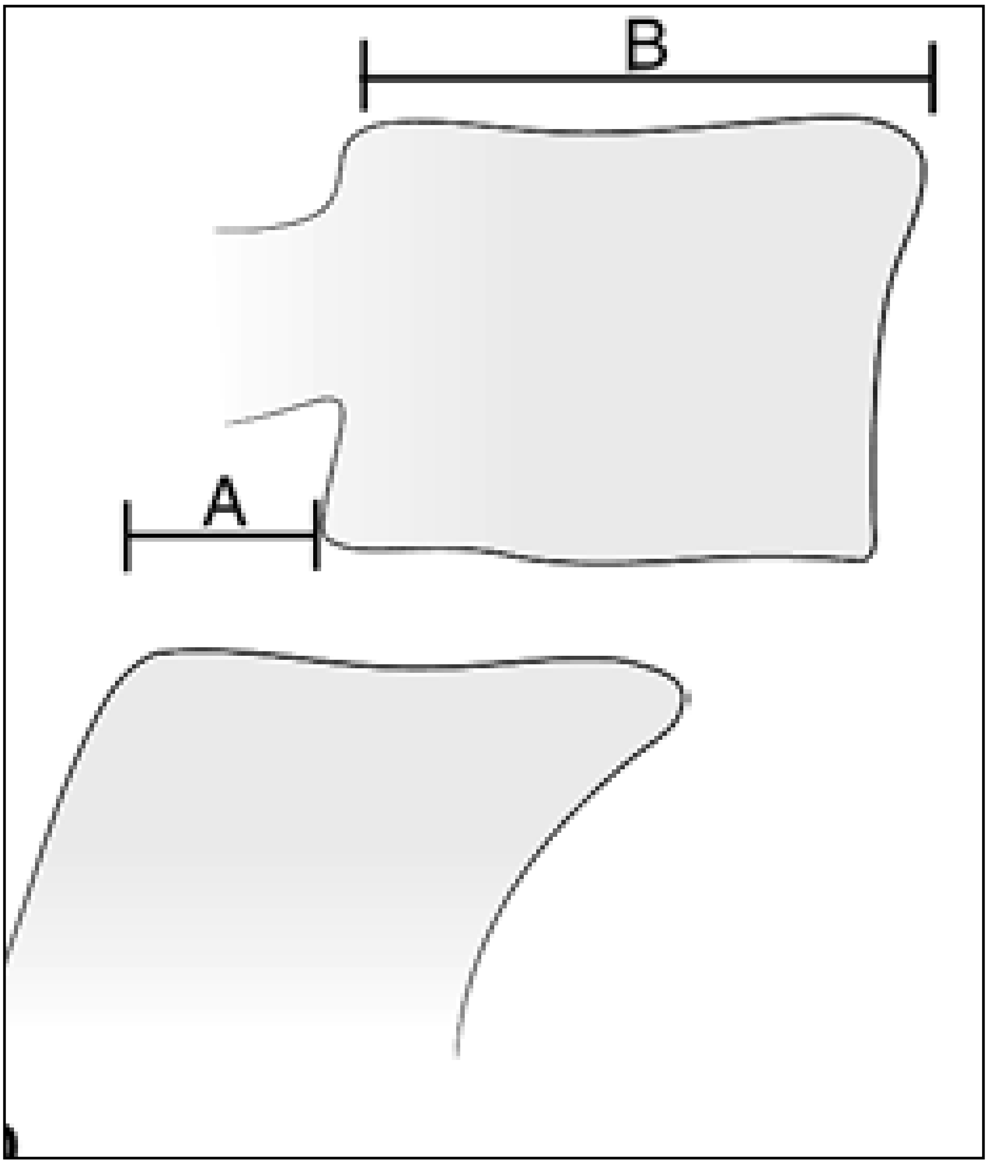


Figure 11.The measurement of the slip percentage by Wright and Bell method.

(Taken from *J Am Acad Orthop Surg* 2012;20: Radiographic analysis of spondylolisthesis and sagittal spinopelvic deformity)

Accordingly the degree of slip may be

Grade 1 : 0-25%

Grade 2 : 25-50%

Grade 3 : 50-75%

Grade 4 : 75-100%

A practically useful recent modification is

Low grade: < 50%

High grade : > 50%

Lumbosacral Angle:

The lumbosacral angle (LSA) is a measure of the sagittal alignment of L5 to S1. It has been variously described by many authors including Wiltse, Boxall, Antoniades, causing much confusion. The method described by Duboussset is more reproducible(44). According to his method, the LSA is the angle formed by lines drawn parallel to the superior endplate of L5 and the posterior aspect of the body of S1.

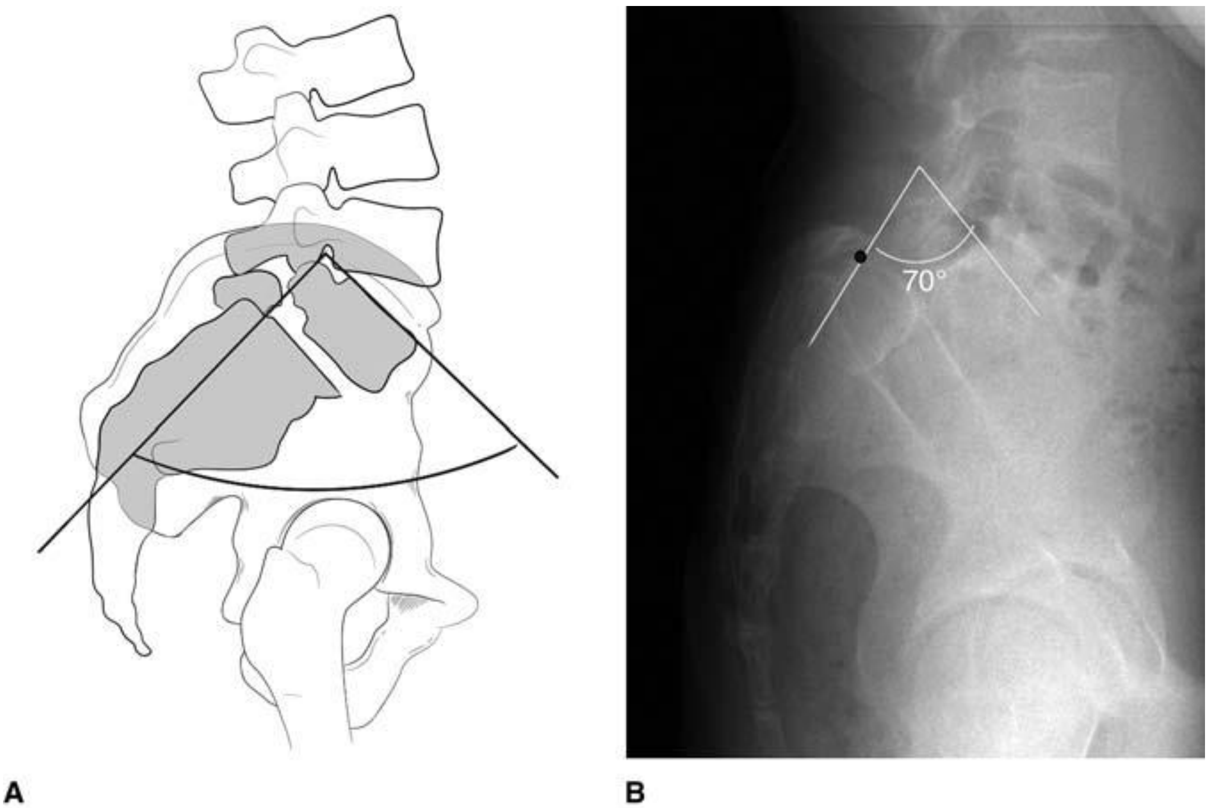
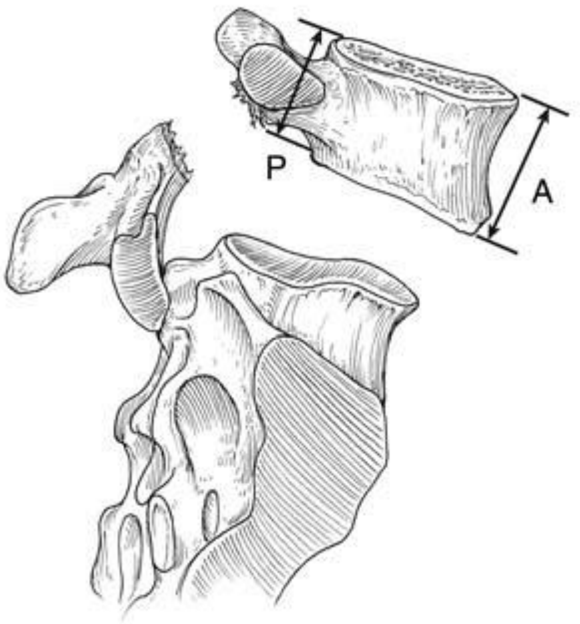


Figure 12. Illustration showing the measurement of lumbosacral angle according to Duboussset (27).

(Taken fromYing Li, MD M. Timothy Hresko, MD Radiographic Analysis of Spondylolisthesis and Sagittal Spinopelvic Deformity. J Am Acad Orthop Surg 2012;20: 194-205.)

Lumbar index:

It is seen that in spondylolisthesis the L5 vertebra is somewhat wedge shaped. The lumbar index is described by Vallois and Lozarthes. It is the ratio of the posterior border of L5 to the anterior border of L5, calculated as percentage. The normal value is around 89. In spondylolisthesis, the values are often less than 70. Wiltse believed this to be the effect of the slip rather than the cause as many authors believed.



LI = P/A x 100 %

Figure 13. showing the measurement of lumbar index(LI). (39)

(Taken fromThomas R. Jones, MD, PhD Raj D. Rao, MD .Adult Isthmic Spondylolisthesis. J Am Acad Orthop Surg 2009;17: 609-617.)

IMPORTANCE OF PELVIC MORPHOLOGY

In the human spine the vertebra forms a smooth multi linkage system, with its various curves. The head is balanced on the cervical spine which articulates with the torso which articulates with the pelvis which in turn articulates with the lower limbs through the hips(7).This system is normally highly energy efficient in maintaining a stable posture with minimum expenditure of energy and muscle strain.

In this respect, it is important to recognise the effect of pelvic morphology on the global spinopelvic balance of the individual. The pelvic morphology determines the position of the sacral end plate on which the thoracolumbar spine rests. The spine reacts to the sacral position through the lumbar lordosis to maintain balance with minimal energy expenditure. Hence the whole spine is a set of closely linked segments in which changes in one segment will result in adaptive changes to the adjacent segments.

Many radiological parameters have been described to quantify the pelvic morphology based on the lateral standing radiographs. Some of the variables are position dependent while others are specific to each individual independent of position of the individual. Duval-Beaupe`re(45) in 1998 described the parameter of Pelvic Incidence (PI). It is the angle between the perpendicular to the sacral end plate and the line connecting the centre of the hip joints to the centre of sacral end plate. PI is independent of the posture of the individual and is specific for each person. The PI describes the relationship of the plane of the sacral end plate to the axis of rotation of the centre of the femoral head(27). PI has been shown to be constant in each individual throughout adulthood. The value of PI is constant in childhood, increases in adolescence and the plateaus in adulthood. PI is thus a reliable measure of the pelvic morphology which is position independent and individual specific.

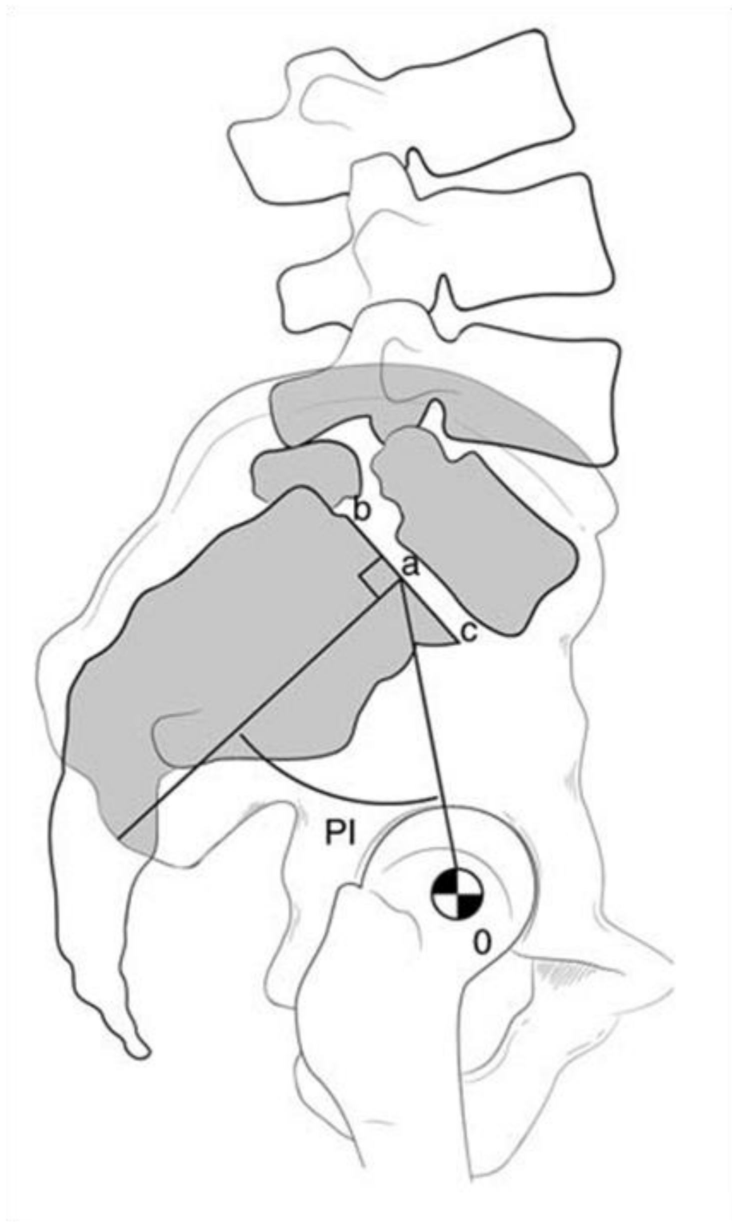


Figure 14. Showing the pelvic incidence angle (27).

(From Ying Li, MD M. Timothy Hresko, MD. Radiographic Analysis of Spondylolisthesis and Sagittal Spinopelvic Deformity. J Am Acad Orthop Surg 2012;20: 194-205.)

The Pelvic Tilt (PT) , is the angle between the line connecting the centre of femoral heads to the centre of the sacral endplate, and the vertical. It is a posture dependent variable. The Sacral Slope (SS) , is the angle between the tangent to the sacral end plate , and the horizontal(27). SS is also dependant on the posture of the individual. PT and SS describe the orientation of the pelvis in the sagittal plane and not its morphology. The terms pelvic anteversion and pelvic retroversion are used to describe the motion of the pelvis about the hip joint in the sagittal plane. Pelvic anteversion refers to anterior PT, and pelvic retroversion refers to posterior PT. Pelvic anteversion results in high SS and low PT, whereas pelvic retroversion results in low SS and high PT(37).

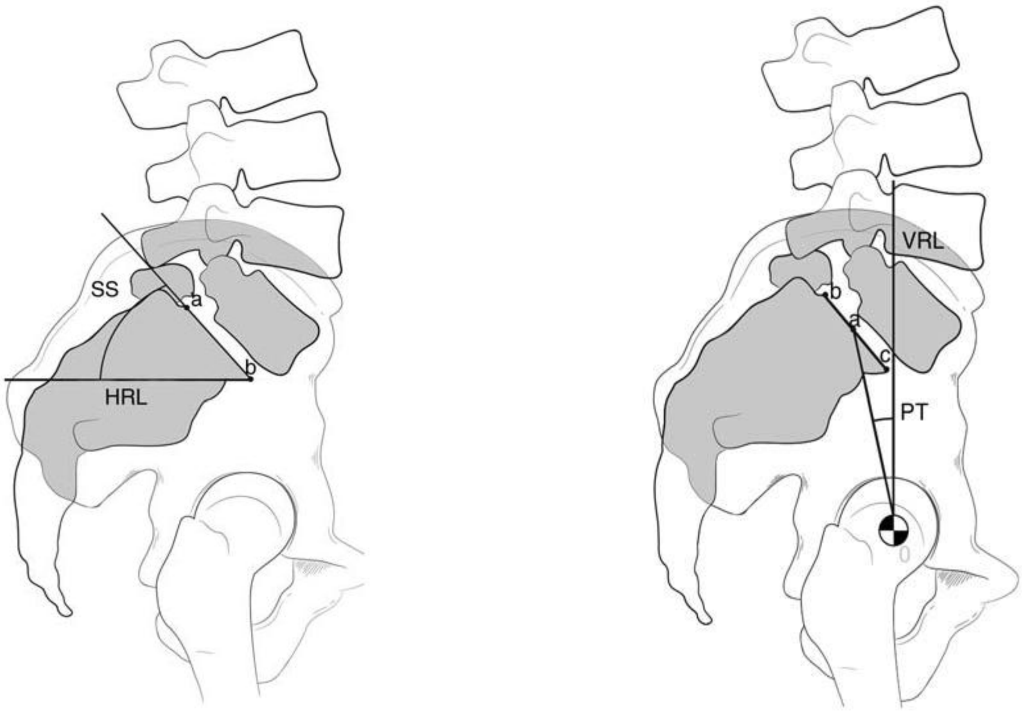


Figure 15. showing the measurement of sacral slope (SS) and pelvic tilt (PT) .HRL is the horizontal and VRL is the vertical (27)(From Ying Li, MD M. Timothy Hresko, MD .Radiographic Analysis of Spondylolisthesis and Sagittal Spinopelvic Deformity .J Am Acad Orthop Surg 2012;20: 194-205.)

It is seen that PI is the arithmetic sum of the SS and PT. As the PI increases, the sacral end plate is more vertical. The spine responds by increasing the lumbar lordosis, which increases the shear forces at the lumbosacral junction(27). This has important implications in the pathogenesis of spondylolisthesis at L5- S1 junction. In the original work by Jean Legaye and Duval Beaupere(45), in 1998, the pelvic incidence is described as the major factor in the sagittal balance of the spine in an individual. As mentioned before, the pelvic incidence is specific to each individual and independent of posture. Duval Beaupere compared the radiographs of forty nine normal adults with sixty six women with scoliosis. They calculated the parameters of pelvic incidence, sacral slope, pelvic tilt and the overhang of the first sacral vertebra over the femoral heads. They concluded that "The orientation of the pelvis determines the sagittal position of the sacral plate in relation to the femoral heads, adapted for each individual by the anatomical parameter "incidence": The higher the value of the "pelvic incidence", the higher the value of the adapted "overhang of S1"." The pelvic incidence is an anatomic parameter which determines the amount of the lordosis - the higher the pelvic incidence, the higher the lordosis and vice versa. This power of the pelvic incidence to determine the sagittal spinal balance is true for normal and scoliotic subjects.

Roussouly et al in 2005(46), described a classification for the normal variations in the alignment of the spine in the standing posture. The coronal alignment of the spine is normal when straight and pathological when curved. But in case of the sagittal alignment there are no fixed standard for the normal and pathological In an early study, Stagnara et al(47) concluded that the "span of possible values of maximum kyphosis and lordosis in subjects with no spinal disease is considerable. . . It is therefore unreasonable to speak of normal kyphotic or lordotic curves." However the Scoliosis Research society (www.srs.org) gives ranges of the normal thoracic kyphosis for adults as 20^0 to 40^0 and that of lumbar lordosis as 30^0 to 80^0 . Most of the degenerative changes occur in the spine that is normal in the coronal plane but pathological in the sagittal plane.

In his study Roussoully(46) studied the lateral full length radiographs of a cohort of one hundred and sixty normal subjects and described the parameters of sagittal spinal alignment in them. They were then grouped into four groups based on these parameters. The cohort consisted of eighty six females and seventy four males who were free of spinal symptoms. The subjects consisted of mainly medical and paramedical personnel from different lineages of Europe. A validated software programme (Sagittalspine , Optimage, Lyon , France) was then used to analyse the sagittal anatomy of the spine. A classification system was made by the Roussoully et al based on the observation that “characteristic sagittal profiles that occur as a consequence of the orientation of the pelvis, sacrum, and lumbosacral junction”. They proposed four types of lordosis, accordingly.

Type 1 Lordosis

Here , the sacral slope is less than 35 degrees and the pelvic incidence is low. Centre of L5 is the apex of the lordosis. As the sacral slope decreases, the lower arc of lordosis also decreases. Inflection point is low and posterior. There is considerable kyphosis of the thoracolumbar junction and upper spine.

Type 2 Lordosis

Here the sacral slope is less than 35 degrees, the base of the L4 vertebra is the apex of the lordotic curve . The lower arc of lordosis is flattened. Inflection point is higher and anterior. There is diffuse hypokyphosis and hypolordosis of the entire spine.

Type 3 Lordosis

Here the sacral slope is somewhere between 35 and 45 degrees. Centre of the L4 vertebral body is the apex of the lordotic curve. Inflection point is at the thoracolumbar junction and lordosis tilt angle is nearly nil. The entire spine is well balanced.

Type 4 Lordosis

There is a high pelvic incidence and the sacral slope is greater than 45 degrees . The base of L3 vertebral body is the apex of the lumbar lordosis. Lordosis tilt angle is zero or positive. Upto five vertebrae are involved in the lordosis and there is a general trend toward segmental hyperextension.

This study has proposed four categories for lumbar lordosis . They concluded that the general assumption that the spine is kyphotic from the first to the twelfth thoracic vertebrae and that it is lordotic from the first to fifth lumbar vertebra is an over simplification of the anatomy. The actual kypholordotic segmentation depends on the orientation of the sacral slope and the pelvis. The lower arc of the lumbar lordosis is the most important determinant of global lordosis. The upper arc of the lumbar lordosis is fairly constant at around twenty degrees in all categories. When the sacral slope is less than thirty five degrees and the pelvic incidence is low, there is a relatively flat and short lumbar lordosis. When the sacral slope is more than forty five degrees and the pelvic incidence is high there is a long curved lumbar lordosis.

The sagittal spinopelvic balance is also important from the perspective of the surgeon doing total hip replacement (THR). The positioning of the acetabular cup in

THR is a major determinant of the short term and long term functional outcome of the prosthesis.

Malpositioning of the cup can lead to dislocation, impingement and increased wear in the long term. Conventionally the cup is recommended to be placed in the safe position of inclination 40+/- 10 degree and an anteversion of 10+/- 0 degree. The reference point for the positioning of the cup is the anterior pelvic plane (APP) which is formed by the line joining the anterior superior iliac spine to the pubic tubercles. The APP is a local pelvic reference system. It was assumed to be horizontal in supine and vertical in standing position, independent of age and sex. Further research has demonstrated that the APP is dependent on the pelvic rotation with varying degree of tilting during standing in different individuals.

The pelvic sagittal rotation is shown to drastically affect the spatial postion of the acetabulum. A forward rotation or flexion of the pelvis with the ASIS rotating more anteriorly produces greater retroversion of the acetabulum. This can lead to posterior uncoverage of the head and anterior impingement. A backward rotation or extension of the pelvis with backward rotation of the ASIS produces a greater anteversion of the acetabulam which technically can lead to anterior uncoverage of the head and greater chance of posterior impingement.

Jean Legaye in 2009(48) made an attempt to correlate the anterior pelvic tilt to the pelvic and spinal sagittal parameters so as to provide a guidance on the individual variation of the acetabular orientation according to the pelvic malrotation. He studied radiographs of two hundred and twenty three normal subjects and one hundred eighty three subjects with back pain. The radiographs were standing lateral views showing the spine , pelvis and proximal femora. For each subject the anterior pelvic plane inclination was compared to the pelvic and spinal parameters. They derived the theoretical sacral slope and the theoretical lumbar lordois from the pelvic incidence using standard equations. The difference between the observed and theoretical values are suggestive of the pelvic malrotation. They demonstrated that there was pelvic malrotation in significant percentage of the low back pain group. This malrotaion could be either anteversion with forward pelvic rotation or retroversion with posterior pelvic rotation. The subjects with low back pain are mostly of the age group requiring the hip arthroplasties. Hence adjustments in the cup postioning depending on the pelvic rotations is advisable for longer lasting prosthesis in THRs.

An association between PI and spondylolisthesis has been reported in many publications. These authors have all have noted a greater PI and SS and postulate that this increased PI could predispose to spondylolisthesis. These radiologic parameters , describing the shape and orientation of the pelvis and sacrum, have been analyzed and found to be significantly different in the spondylolisthesis population when compared to the normal controls. It remains, however, unknown if these changes are primary, and thus involved in the etiology of the disease or simply secondary adaptive changes associated with the progression of spondylolisthesis.

The evaluation of these parameters of pelvic morphology ,rather than the lumbosacral junction alone , in spondylolisthesis is useful from the treatment perspective also as it is shown that restoration of normal sagittal spinopelvic balance is associated with better functional outcomes. This is especially true for a surgeon intending to do a partial reduction in the management of a high grade spondylolisthesis. In high grade spondylolisthesis, the sacral slope is increased, the lumbar spine responds with increase in the lumbar lordosis, which is limited by the facet joints. Further compensation would require retroversion of pelvis and increase in the pelvic tilt. This leads to abnormal posture wih hip and knee flexion. Reduction of the spondylolisthesis to restore normal spinopelvic balance has definite role in reducing residual pain and restoring posture(49).

The present study was done in order to examine the spinopelvic balance parameters in patients with spondylolisthesis and patients with normal spine radiographs. Such parameters have not yet been studied among Indian patients, as far as the author's knowledge goes. It is possible that there may be racial differences in the anatomic range of these parameters. This study attempts to throw light on the radiological parameters that influence development and progression of spondylolisthesis among patients visiting a tertiary care centre in South India.

METHODOLOGY AND MATERIALS.

This study is a retrospective radiological analysis of patients who attended the outpatient services of various units of the Department of Orthopaedic Surgery in Christian Medical College Vellore during the years 2010 to 2012. The medical records were studied and patients with a diagnosis of isthmic spondylolisthesis were included in one arm and patients with back pain with no spondylolisthesis were included in the other arm.

The inclusion criteria for the spondylolisthesis group included age between 20 to 40 , availability of standing radiographs which clearly visualized the region between upper border T12 vertebral and the femoral heads. Radiographs that did not show the femoral heads in overlap were also included. Patients having degenerative changes, listhesis at levels other than L5-S1 , multilevel spondylolisthesis , patients with history of significant trauma to the spine, infectious , primary or secondary neoplasm were excluded from the study group. Patients with radiographs taken prior to 2010, but who came to outpatient services for follow up between 2010 and 2012 were also included in the study. The latest pre-operative X-rays were taken for study.

The control group was selected from patients who presented with back pain but who had no spondylolisthesis clinically or radiologically. Patients were then included based on the availability of standing lumbosacral radiographs where the femoral heads were visualized well. The age group of these patients was 20 to 40 , like the study group.

The X-rays were taken by a single Philips DR Eleva machine (Philips Healthcare, Andover, MA) .All X-rays were taken following standard protocol with the patient in standing posture with knees and hips in extension, and the hand resting on the clavicles. The X-ray beam was placed at a standard distance of 110 cm from the patient .

All X-rays were uploaded to the hospital picture archiving and communication system (PACS). The X-rays were then downloaded to another computer. The images were imported into Microsoft Power Point (Microsoft Corporation, Redmond, VA) .The sacral end plate was marked using Microsoft power point tools. The bisector to the sacral end plate was drawn to mark its centre. The femoral heads were marked and their centres identified using Microsoft power point tools. In cases where the femoral heads were not overlapping, the individual centre of heads were connected and a bisector drawn to the same to identify the centre. The angles were measured with an MB tool software, available as a freeware download from the internet (http://www.markus-bader.de/MB-Ruler/) The angles measured were the pelvic incidence (PI), the sacral slope (SS) , the pelvic tilt (PT), and the lumbar lordosis (LL). The lumbar index of the L5 vertebra was also measured.

Pelvic incidence- A line was drawn perpendicular to the middle of the sacral end plate. Another line was drawn from the centre of the sacral end plate to the centre of the femoral heads. The angle between these two lines would give the pelvic incidence.

Sacral slope- A line was drawn along the upper border of the sacral end plate . The angle between this line and the horizontal is the sacral slope.

Pelvic tilt- angle between the vertical line and the line joining the middle of the sacral plate and the axis of the femoral heads.

Lumbar lordosis- This is measured using the Cobb's constrained Method. A line is drawn along the the superior endplate of the twelfth thoracic vertebra. A similar line is drawn along the superior end plate of first sacral vertebra. The angle between the lines is the lumbar lordosis.

Figure 16. showing the measurement of PI and LL in a patient with spondylolisthesis . The points are marked using Microsoft power point tools and lines are drawn . The angles are measured using MB tool software.

The Grade of slip- This was calculated according to Taillard's modification of Meyerding's Method(50) . The percentage of slip was measured from the posterior end of S1 to the postero-inferior end of L5, and expressed as a percentage of the total length of the S1 upper end plate. A slip percentage of 0-25 is grade1, 25-50 is grade 2, 50-75 is grade 3, 75-100% is Grade 4.

Lumbar index- This was obtained by dividing the height of the posterior cortex of the L5 vertebra with the height of the anterior cortex.

The data were entered into excel spread and subject to Statistical analysis using SPSS software (IBM SPSS Statistics, IBM Corporation, NY).

RESULTS

The spondylolisthesis group 45 patients, with 16 males & 29 females. Of the 45 patients, 17 (37.8 %) had grade 1 spondylolisthesis, another 17 had grade 2 spondylolisthesis, 8 (17.8%) had grade 3 spondylolisthesis, & 3 (6.7%) had grade 4 spondylolisthesis. The control group also had a total of 45 patients, with 26 male and 19 females. The mean age for the spondyolisthesis group was 30.89 with standard deviation of 5.445. The mean age for control group was comparable at 30.47 with standard deviation of 5.941.

The mean value of PI in the spondylolisthesis group was 59.1 standard deviation of 12.84, for SS it was 39.57 with standard deviation of 9.91, for PT it was 19.99 with standard deviation12.8, for LL it was 53.09 with standard deviation 15.13.

The mean value of PI in the control group was 50.75 standard deviation of 8.85, for SS it was 37 with standard deviation of 7.5, for PT it was 11.2 with standard deviation8.2, for LL it was 52.29. with standard deviation 10.2.

Graphical representation of the various variables and the frequency showed normal distribution pattern in all four variables in spondylolisthesis and the control group. Hence the student t test for independent variables was used to compare the PI,SS , PT & LLof the spondylolisthesis and the control group.

Table 2. Distribution of study population based on sex

Group	Male/Female	Frequency	Percentage
Spondylolisthesis	Male	16	35.6
	Female	29	64.4
	Total	45	100
Control	Male	26	57.8
	Female	19	42.2
	Total	45	100

Table 3.

Distribution of patient according to Meyerding grade in spondylolisthesis group

Grade	**Frequency**	**Percent**
Grade 1	17	37.8
Grade 2	17	37.8
Grade 3	8	17.8
Grade 4	3	6.7

Table 4. Group statistics of PI, SS, PT, LL in the spondylolisthesis and control group.

Group			Age	Pelvic_incidence	Sacral_slope	Pelvic_tilt	Lumbar_Lordosis
Diseased	N	Valid	45	45	45	45	45
		Missing	0	0	0	0	0
	Mean		30.89	59.3100	39.57	19.987	53.099
	Median		31.00	57.3000	40.36	18.600	55.870
	Std. Deviation		5.445	12.84393	9.914	12.7945	15.1328
	Minimum		21	30.00	17	.0	3.1
	Maximum		39	95.00	56	54.0	85.0
	Percentiles	25	27.00	50.3850	32.28	10.520	44.115
		50	31.00	57.3000	40.36	18.600	55.870
		75	35.00	66.5950	46.86	28.150	62.455
Normal	N	Valid	45	45	45	45	45
		Missing	0	0	0	0	0
	Mean		30.47	50.7531	37.54	13.421	52.291
	Median		30.00	52.3000	37.00	11.200	51.280
	Std. Deviation		5.941	8.85641	7.510	8.2218	10.2042
	Minimum		21	33.39	20	2.0	29.1
	Maximum		40	70.00	50	37.3	74.2
	Percentiles	25	25.50	43.3750	31.50	6.920	46.000
		50	30.00	52.3000	37.00	11.200	51.280
		75	36.00	56.6350	45.00	19.100	60.000

Table 5. Statistics of the Lumbar index (LI) in the spondylolisthesis and control group.

	Group	N	Mean	Std. Deviation	Std. Error Mean
Lumbar Index	Spondylolisthesis	45	.7938	.10913	.01627
	Control	45	.9212	.06648	.00991

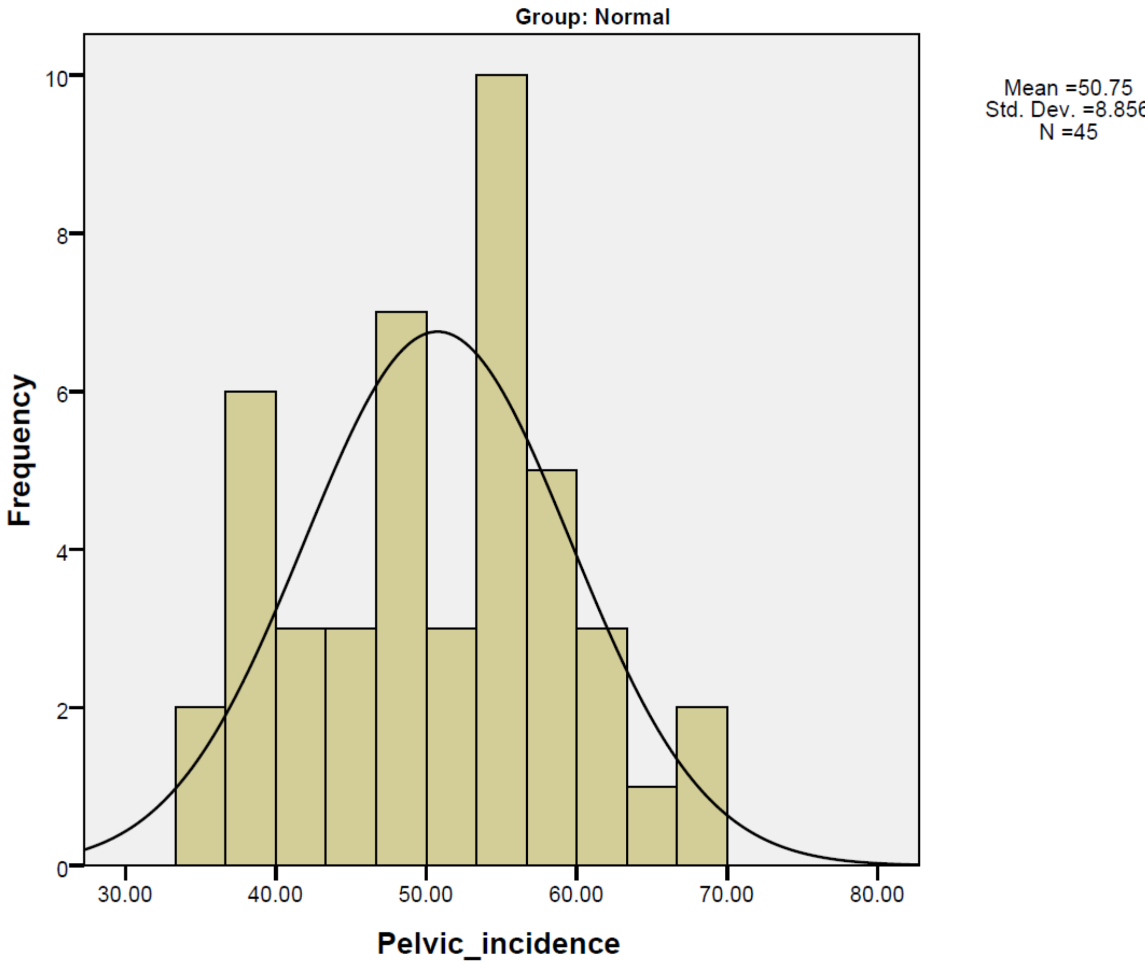


Figure 17. Distribution of PI in control group.

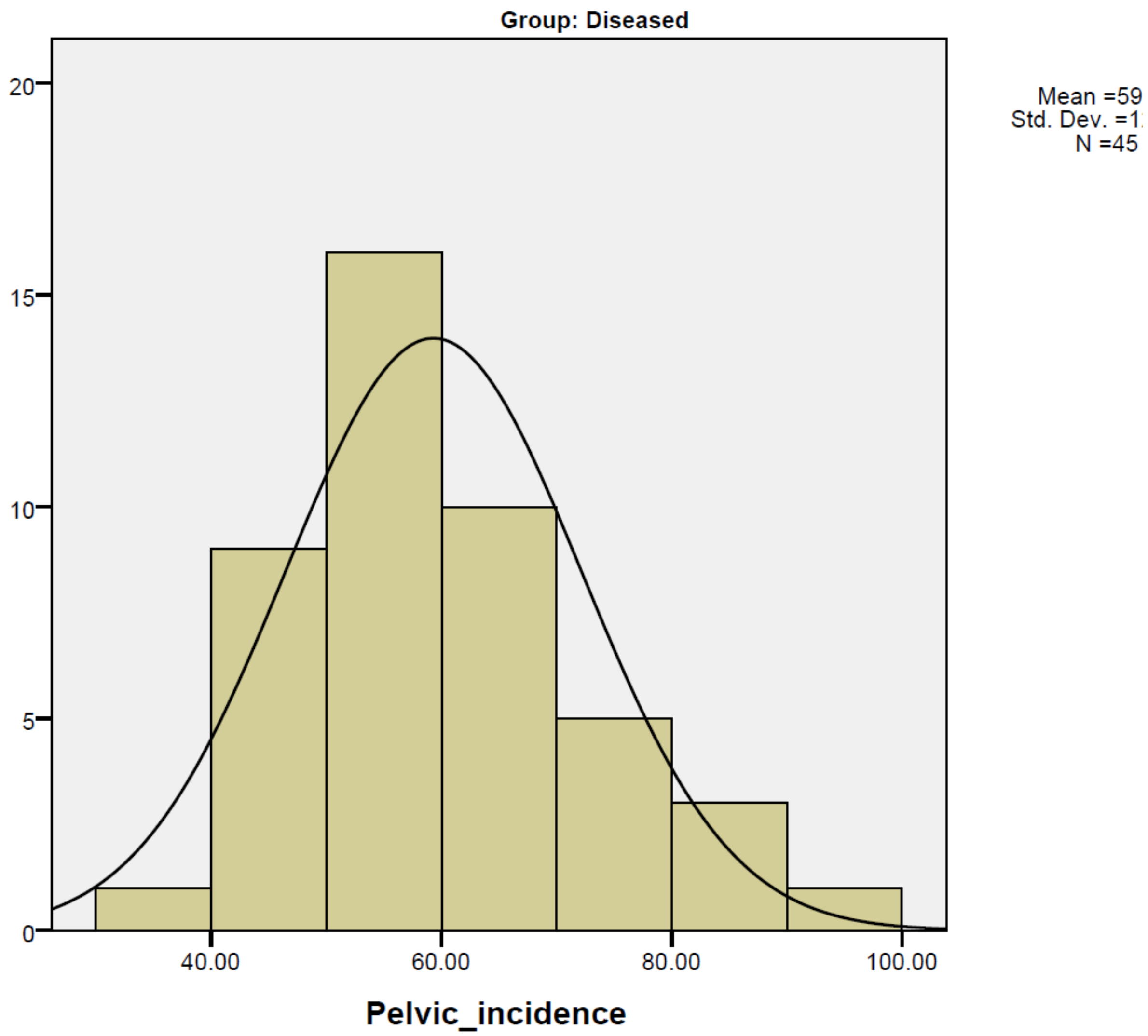


Figure 18. Distribution of PI in spondylolisthesis group.

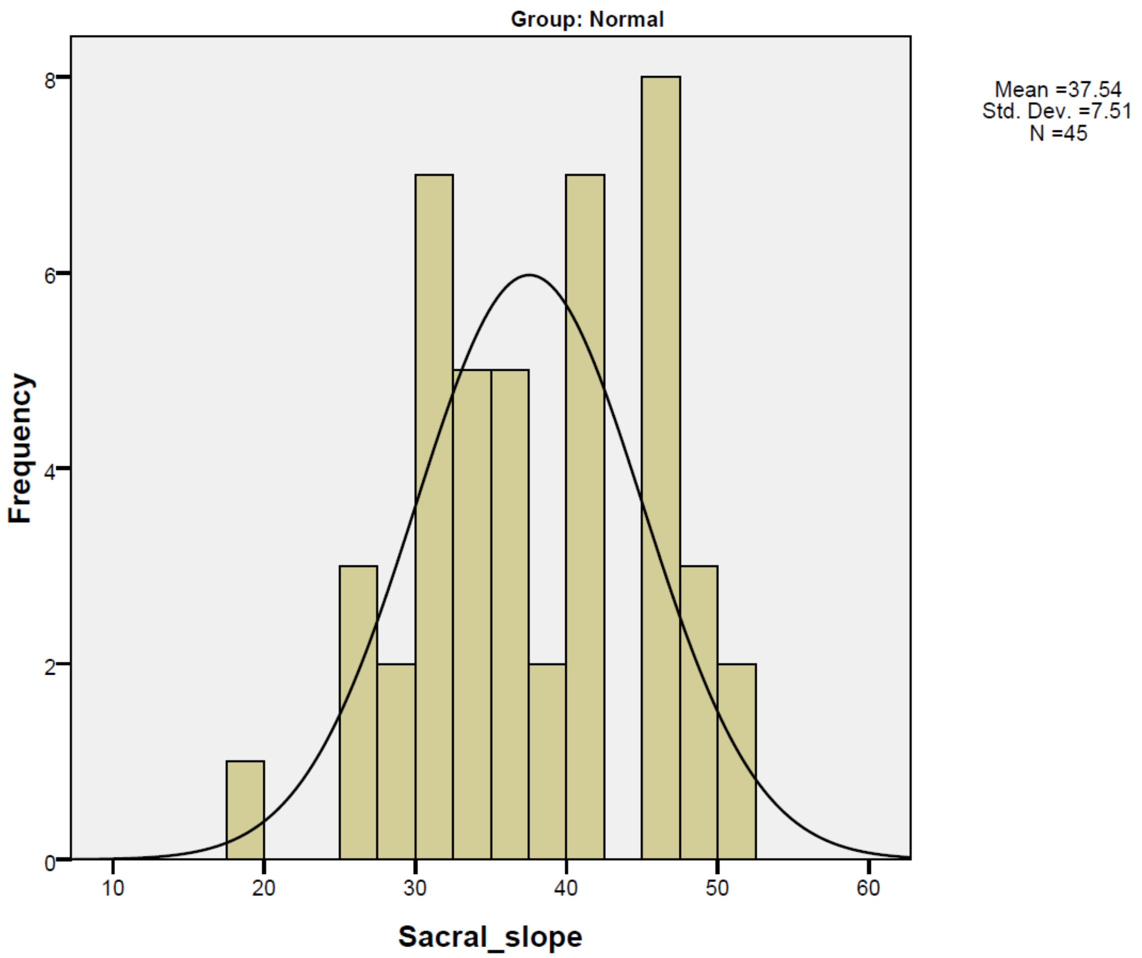


Figure 19. Distribution of SS among control population .

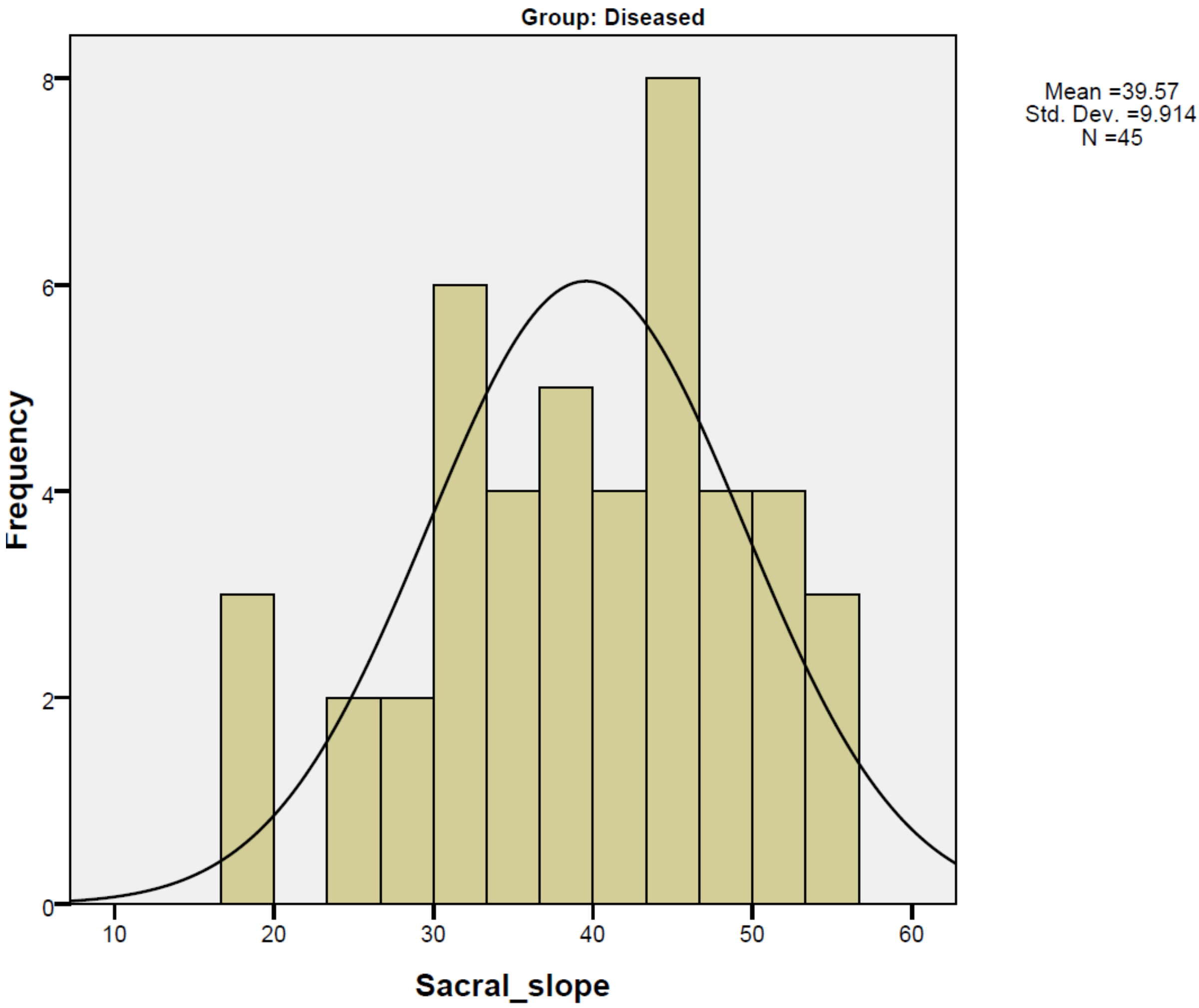


Figure 20. Distribution of SS in spondylolisthesis population.

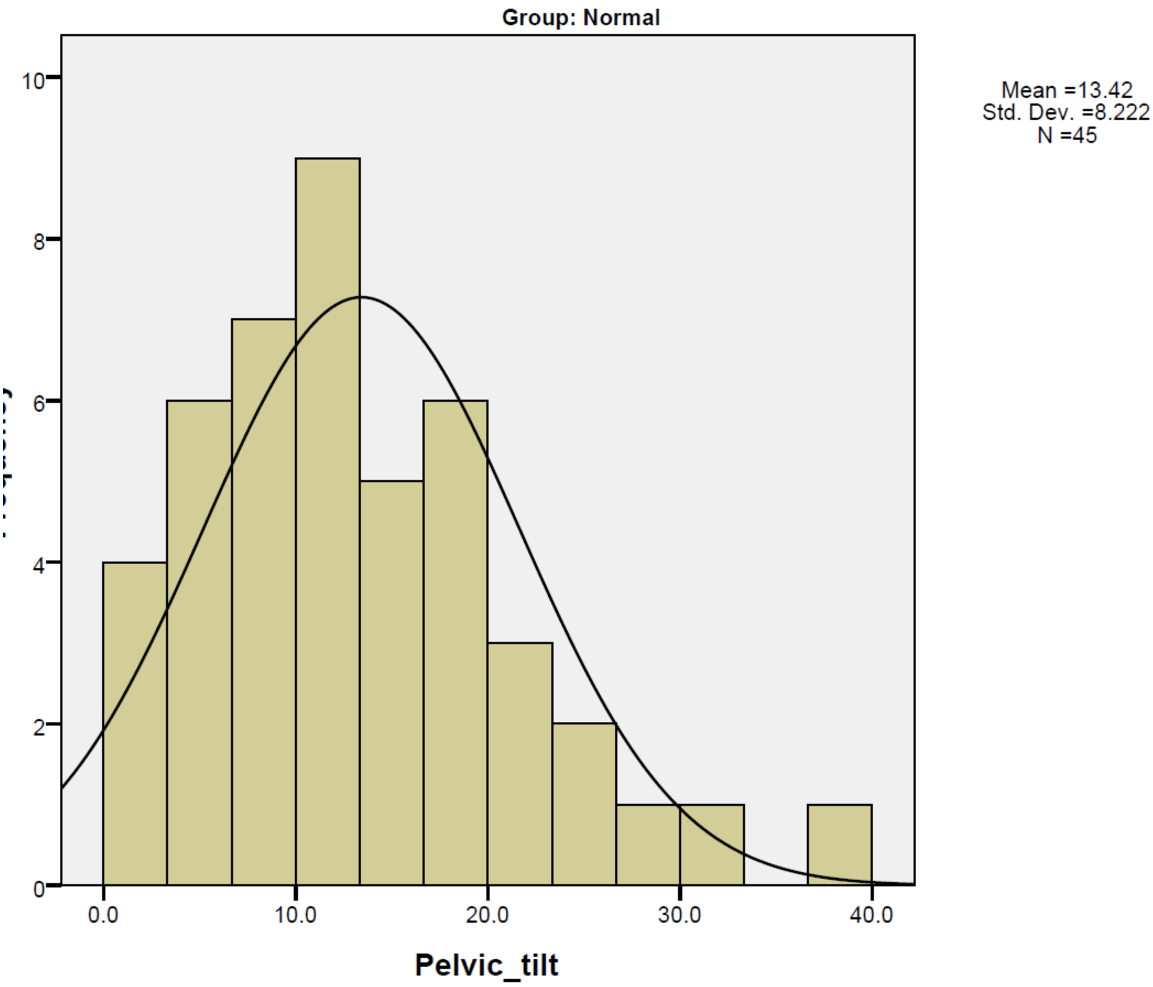


Figure 21. Distribution of PT in control population.

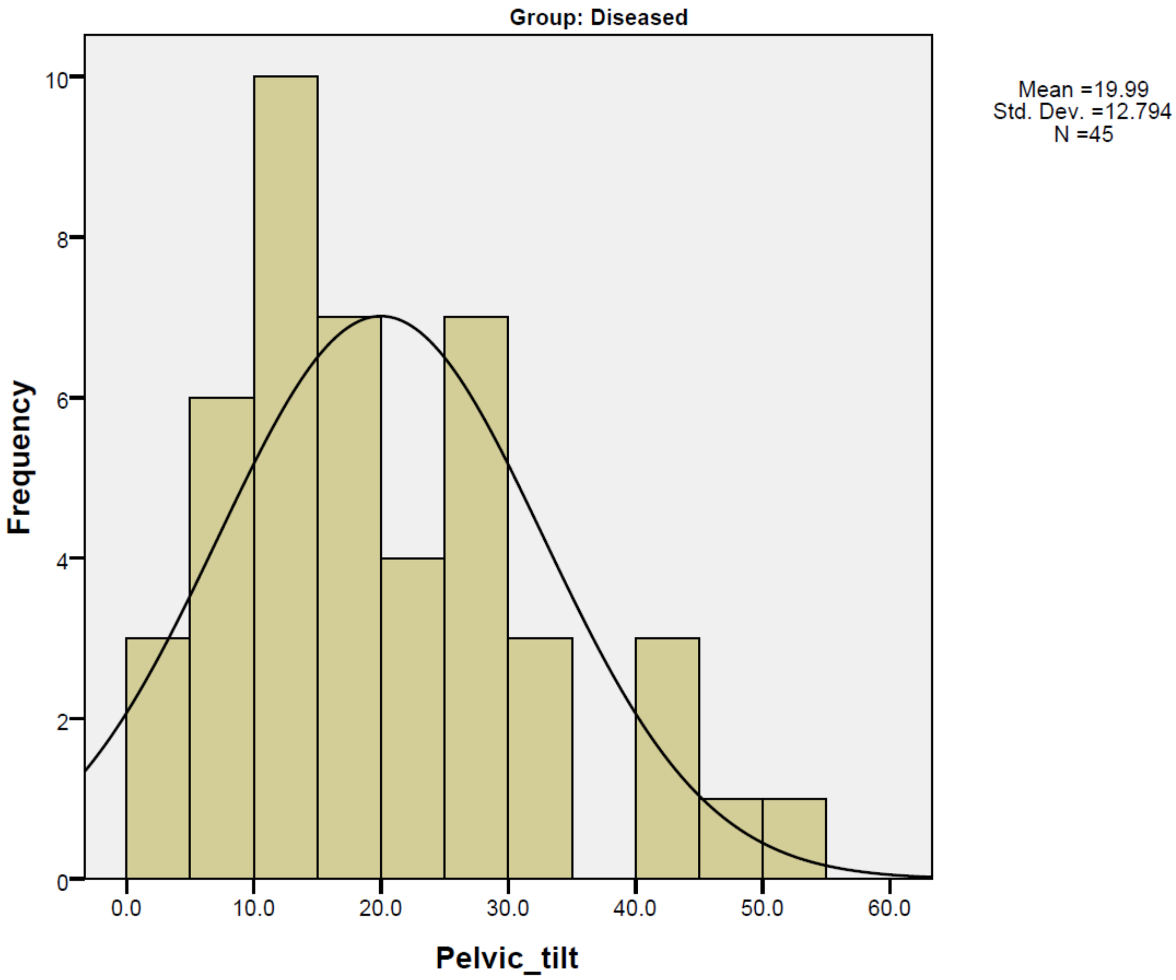


Figure 22. Distribution of PT in spondylolisthesis group.

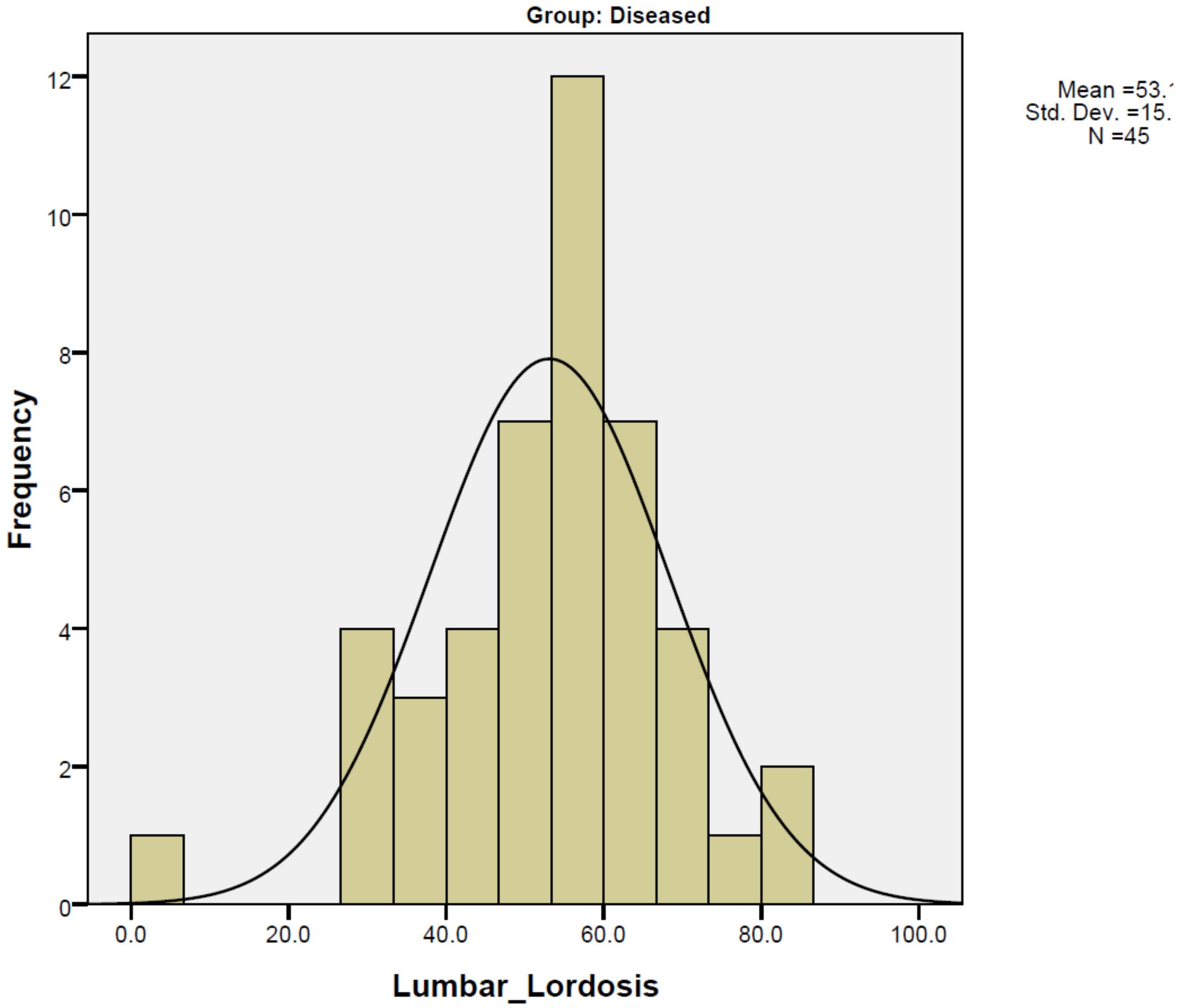


Figure 23. Distribution of LL in spondylolisthesis group.

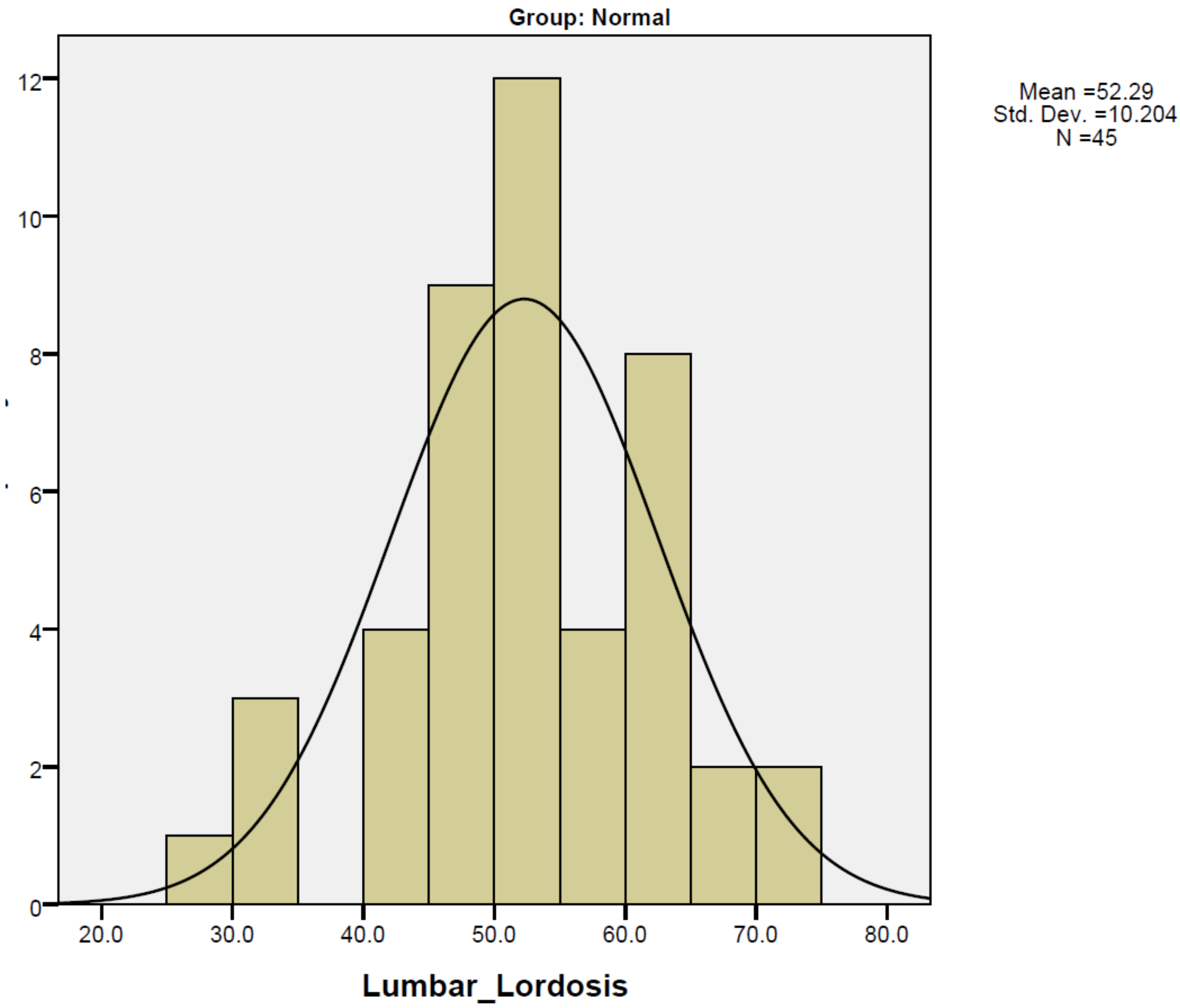


Figure 24 . Distribution of LL in the control group.

Table 6. Showing the independent t test for PI, SS PT & LL.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Pelvic_incidence	Equal variances assumed	3.214	.076	3.679	88	.000	8.55689	2.32571
	Equal variances not assumed			3.679	78.126	.000	8.55689	2.32571
Sacral_slope	Equal variances assumed	2.751	.101	1.096	88	.276	2.032	1.854
	Equal variances not assumed			1.096	81.986	.276	2.032	1.854
Pelvic_tilt	Equal variances assumed	7.617	.007	2.896	88	.005	6.5658	2.2671
	Equal variances not assumed			2.896	75.045	.005	6.5658	2.2671
Lumbar_Lordosis	Equal variances assumed	3.555	.063	.297	88	.767	.8078	2.7208
	Equal variances not assumed			.297	77.158	.767	.8078	2.7208

The analysis showed that the difference in values of PI, PT and LI between the two groups was significant. The p value was .000 for PI and .005 for PT and hence statistically significant. The p value for LI was 0.00. The SS and LL values were not found to be significantly different.

Table 7. showing independent t test for LI.

Independent Samples Test for LI

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Lumbar Index	12.067	.001	-6.690	88	.000	-.12744	.01905	-.16530	-.08959

Table 8. showing the distribution of PI, SS, PT & LL among different grades of spondylolisthesis.

Grade_r		N	Minimum	Maximum	Mean	Std. Deviation
Grade 1	Pelvic_incidence	17	30.00	80.10	54.8076	12.35600
	Sacral_slope	17	19	55	37.65	10.353
	Pelvic_tilt	17	.0	48.0	17.656	14.4826
	Lumbar_Lordosis	17	3.1	71.0	50.415	17.8078
	Lumbar Index	17	.70	.99	.8371	.07060
Grade 2	Pelvic_incidence	17	41.00	95.00	60.0418	13.96138
	Sacral_slope	17	17	56	40.72	11.647
	Pelvic_tilt	17	5.3	54.0	19.435	12.7529
	Lumbar_Lordosis	17	28.0	85.0	55.814	16.3262
	Lumbar Index	17	.62	.94	.8041	.09721
Grade 3	Pelvic_incidence	8	47.30	83.50	63.0762	10.21639
	Sacral_slope	8	31	48	40.18	6.737
	Pelvic_tilt	8	12.0	41.5	22.960	10.6770
	Lumbar_Lordosis	8	38.0	60.8	52.375	8.1591
	Lumbar Index	8	.59	.92	.7162	.12906
Grade 4	Pelvic_incidence	3	63.40	78.50	70.6333	7.56990
	Sacral_slope	3	41	45	42.35	2.295
	Pelvic_tilt	3	22.4	33.8	28.400	5.7448
	Lumbar_Lordosis	3	52.3	56.4	54.853	2.2633
	Lumbar Index	3	.50	.86	.6967	.18230

The mean values of the variables for each grade of slip in the spondylisthesis group were compared. It was found that PI and PT have a positive linear correlation with the grade of spondylolisthesis with mean values increasing from grade 1 to grade 4.

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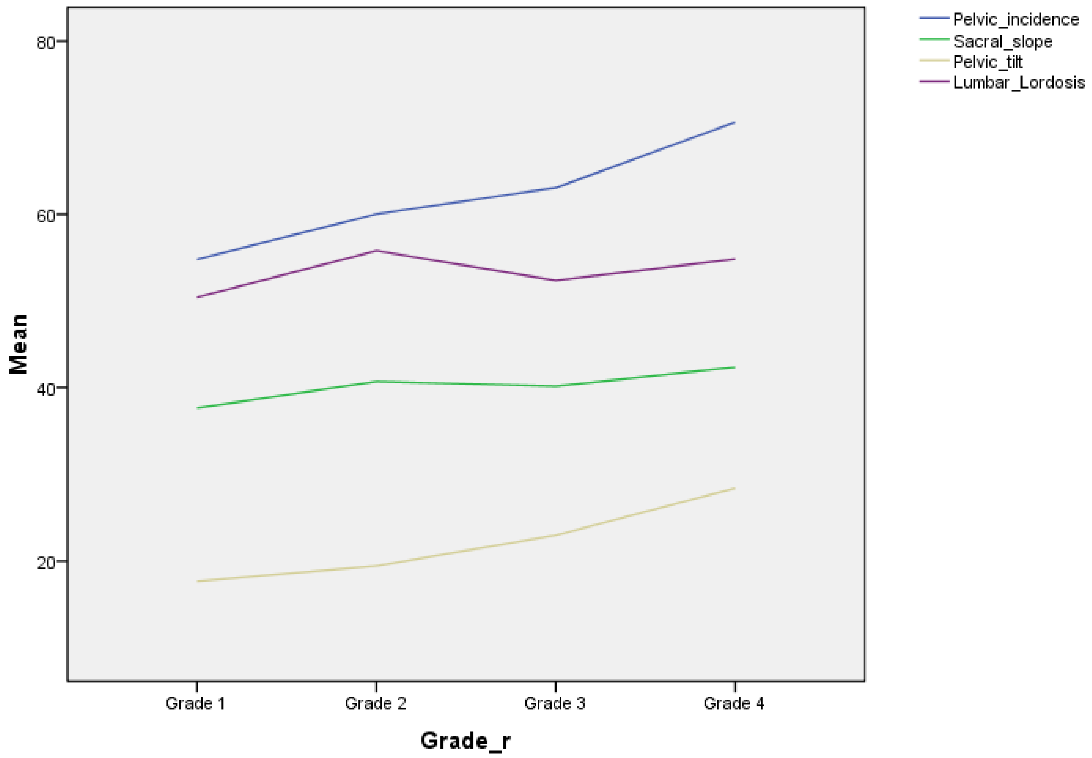

Figure 25. Showing graphical representation of PI, SS , PT & LL among the different grades of spondylolisthesis.

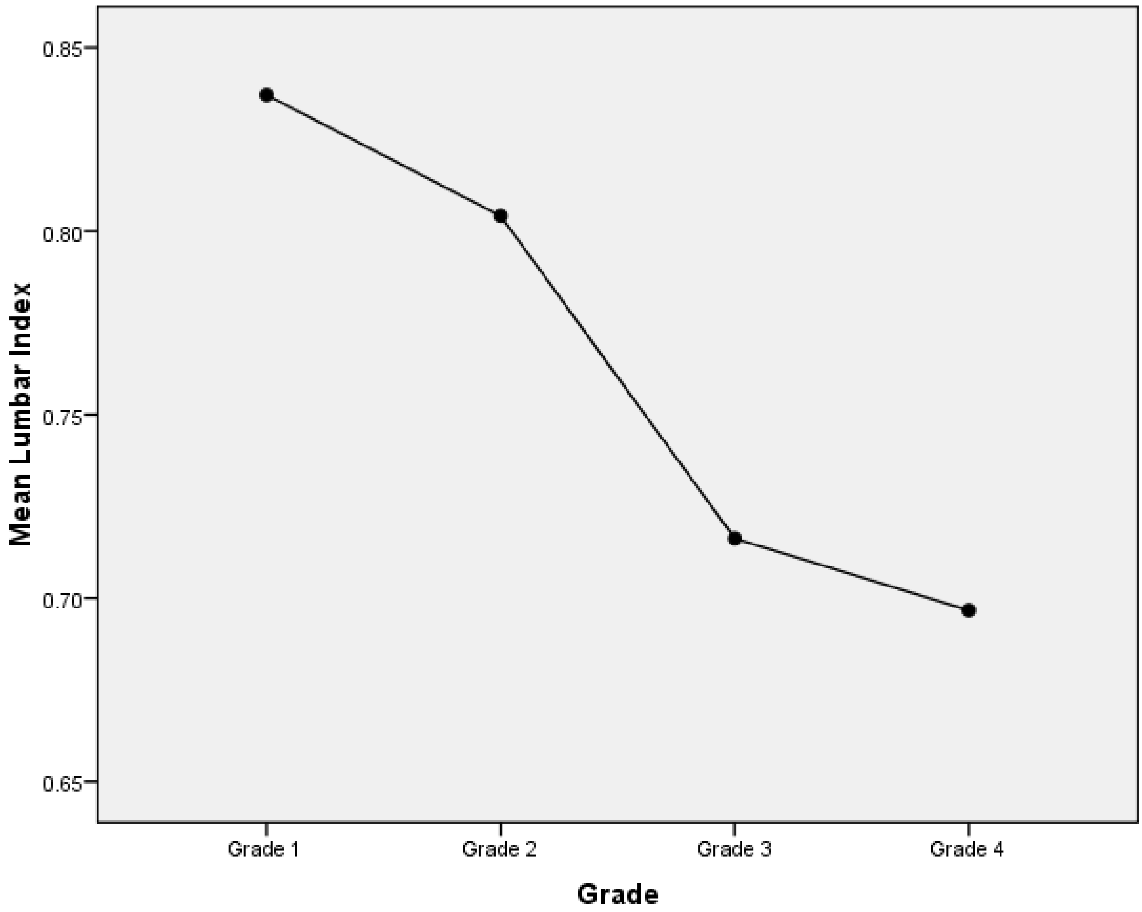

Figure. 26 showing the mean value of LI was found to have negative correlation with Grade, the value of LI decreasing from grade 1 to 4.

Table 9 Showing distribution of PI, SS, PT & LL between male and female within the control group.

Sex		N	Minimum	Maximum	Mean	Std. Deviation
Male	Pelvic_incidence	26	33.39	70.00	48.5254	9.44124
	Sacral_slope	26	20	50	37.21	7.838
	Pelvic_tilt	26	2.0	33.0	11.697	7.9697
	Lumbar_Lordosis	26	29.1	70.8	51.892	11.0129
	Valid N (listwise)	26				
Female	Pelvic_incidence	19	38.84	67.58	53.8016	7.13814
	Sacral_slope	19	27	50	37.99	7.222
	Pelvic_tilt	19	2.9	37.3	15.782	8.1760
	Lumbar_Lordosis	19	31.0	74.2	52.837	9.2487
	Valid N (listwise)	19				

The value for the PI, SS, PT & LL were compared between the male and female patients of the control group. The mean PI in maleswas 48.52 and in females was 53.8 (p value 0.047). The mean value of PT in male was 11.697, and in females was 15.72. The differences in values forPI and PT was found to be significant as evidenced by the t test.

DISCUSSION

It is the characteristic human posture to stand erect with extension at the spine, hips and knees. This has led to the lumbar lordosis which is not found in lower animals. The whole spine is a group of interlinked units that has its base at the pelvis. The pelvis as a whole can be considered a single spinal vertebral unit. The spatial orientation of the pelvis determines the spatial orientation of the rest of the spine. The pelvic incidence,(PI) and sacral slope (SS)are parameters of the sagittal orientation of the pelvis that determine the sagittal morphology of the whole spine. Of these, the pelvic incidence is a position independent, variable that is specific to any individual. It does not change after adulthood.

The PI and SS are important in determining the type of lumbar lordosis that is specific to a person. An increasing slope increases the lumbar lordosis The global forces acting on a spinal segment can be shearing or vertical pressure depending on the tilt of the vertebra .The vertical pressure forces act on the vertebra bodies and discs while the shear forces predominantly act on the posterior elements. A higher PI results in higher SS, leading to increased lumbar lordosis, which in turn leads to higher shear forces at the posterior elements of the spino-pelvic junction. This can theoretically increase the risk of isthmic spondylolisthesis. The present study was an effort to delineate the association of pelvic parameters with spondylolisthesis.

In 1998, Legaye& Duval –Beaupere in their, landmark paper(45) described the parameter of pelvic incidence. They had compared the sagittal spinal parameters of 49 normal subjects to 66 patients with scoliosis. They measured the PI as the angle between the perpendicular to the sacral plate at its midline with the line joining the midpoint to the axis of the femoral heads. They described the PI as - “It is an anatomical parameter, unique to each individual, independent of the spatial orientation of the pelvis". The PI is dependent on the anatomy of the pelvis, mainly the first three sacral vertebrae, the sacroillliac joints, and the posterior aspect of the iliac bones. The mobility at SI joint being considered negligible, the PI is independent of the position of the pelvis in space. In their study, Legaye et al found the mean Pelvic incidence as 53.2 (SD 10.3), in men and 48.2 (SD 7.0) in women . The mean PI values in our study for the control group in males was 48.52(SD 9.4) and in females was 53.8.(SD 7.1). They concluded that the PI is the key anatomic factor that regulates the sagittal curves of the spine in both normal and scoliotic subjects. This harmonious regulation brings about an energy efficient balance that maintains the weight forces sufficiently behind the lumbar spine and the coxofemoral axes.

In a study by Curylo et al(51)in 53 patients with spondyloptosis, it was concluded that pelvic incidence is the major parameter of spino pelvic anatomy that determines the risk of progression of low grade spondylolisthesis to high grade spondylolisthesis and spondyloptosis. Their mean value for PI was 76 which is significantly more than the PI values for normal and low grade spondylolisthesis. They postulate that patients with spondyloptosis initially had lower grades of spondylolisthesis. Over a period of time, they progress to higher grades of spondylolisthesis, with adaptive changes in the lumbar lordosis , pelvic tilt etc. Hence the lumbar lordosis and pelvic tilt measurements are inaccurate to predict the original spinopelvic balance.

The pelvic incidence , on the other hand is an anatomic parameter, specific to each individual , which does not alter after the age of ten. The high PI in an individual makes the sacral end plate more vertical, resulting in increased lumbar lordosis and higher shear forces at the lumbosacral junction. Curylo et al (51) conclude that high PI with posterior element dysplasia contribute to the progression of low grade spondylolisthesis. They recommend identification of patients with high PI so that treatment and follow up can be altered at an earlier stage without risking complicated procedures in higher slip grades.

Hanson et al(52) in 2002 compared PI values in 40 patients with spondylolisthesis with a control group of 20 adults and 20 paediatric subjects. Mean PI was 47.4° in the paediatric control group, 57° in the adult control group, 68.5° in the low-grade isthmic spondylolisthesis group, and 79.0° in the high-grade isthmic spondylolisthesis group. They found that PI values were significantly higher in the spondylolisthesis group and that it correlated positively with Meyerding Newman grades of spondylolisthesis. They concluded that pelvic incidence values above 68.5 degrees strongly correlated with degree of slip (P=.03) .

Raphael Vialle et al(53) studied the parameters of sagittal balance in 244 patients with spondylolisthesis and compared with 300 control subjects. The mean PI in the control group was 54.67 and the spondylolisthesis group was 73.05. The mean pelvic tilt was 13.21 in controls and 26.53 in spondylolisthesis respectively. They concluded that “this higher than normal lumbar lordosis associated with L5–S1 spondylolisthesis is secondary to the high PI and is an important factor causing high shear stresses at the L5–S1 pars interarticularis”.

In a review article in 2011, Huec et al(54) concluded that pelvic parameters affect the entire sagittal spinal profile. Rajnics et al(55) studied the sagittal spinopelvic parameters in 30 healthy individuals and compared with 48 subjects with spondylolisthesis. They found that the PI and SS were higher in spondylolisthesis patients. Rajnics postulated that the sacrum was more horizontal in these patients. This together with the hyperlordosis caused the shearing force of gravity to be higher than the compressive forces. The two acetabula and hips are positioned well anterior to the lumbosacral junction. The L5 vertebra slips anteriorly to regain balance by maintaining gravity line above the hips.

Marty, Descamps with Legaye, Duval- Beaupere(56), in 2002 studied the anatomy of the sacrum, pelvic parameters in infants, young adults, and patients with isthmic spondylolisthesis. According to them, the sacral anatomy is an important factor in determining the incidence and the sagittal spinal balance. They found that the sacral anatomy is different in spondylolisthesis – "Thus, the sagittal morphology of the first two sacral vertebrae is clearly abnormal, with the sacral plate and the inferior plate of S2 tending to be less backward convergent than among normal adults". They concluded that the organisation of spinal curves could be followed up by looking at the anatomy of the sacrum.

In 2003, Jakson et al(57) did a study comparing pelvic parameters of seventy five patients with spondylolisthesis , with that of normal volunteers. The inclusion criteria for the spondylolisthesis group was more than ten percent spondylolytic slip at L5- S1 junction. They used a different measurement other than the pelvic incidence , called the pelvic lordosis angle. They concluded that pelvic anatomy is a definite causative factor in spondylolisthesis.

In 2004, Hubert Labelle et al (58) , compared the sagital spinopelvic parameters of two hundred and fourteen subjects with isthmic spondylolisthesis , with those of one hundred and sixty normal subjects. The mean PI was 71.6 (SD 7.7) in spondylolisthesis and 51.8 (SD 5.8) in normal subjects. The mean SS was 49.4 (SD 5.9) and 39.7 (SD 4.1) in spondylolisthesis and normal subjects respectively. The Pelvic tilt was 22.2 (SD 6.3) and 12.1 (SD 3.2) in spondylolisthesis and normal subjects respectively. The lumbar lordosis was 66 (SD 8.7) and 42.7 (SD 5.4) in spondylolisthesis and normal subjects respectively. They demonstrated that the values of pelvic incidence, sacral slope, pelvic tilt, and lumbar lordosis were significantly higher in the spondylolisthesis group. Within the spondylolisthesis group, these values showed increasing trend as the severity of spondylolisthesis increases.

Our study had a sample size of 45..The control population in our study was from patients who had come with back pain , but did not have evidence of spondylolisthesis. The ideal control population would have been subjects with no spinal complaints, as is in all the studies examined in the above discussion. Due to the ethical issues involved in exposing asymptomatic people to the hazards of radiation, this drawback was accepted.

The mean value of PI in the control group was 50.75 with standard deviation of 8.85, for SS it was 37 with standard deviation of 7.5, for PT it was 11.2 with standard deviation8.2, for LL it was 52.29. with standard deviation 10.2. It is seen that these values are comparable to the values obtained by Hubert Labelle et al in the cohort of 160 normal subjects . Their mean PI was 51.8 (SD 5.8) SS was 39.7 (SD 4.1) PT was 12.1 (SD 3.2) and LL was and 42.7 (SD 5.4) . Only the lumbar lordosis was higher in our control population.

The study by Macthiong , et al in 2011 (59)described the pelvic parameters in a large cohort of seven hundred and nine asymptomatic individuals . This is the largest cohort described so far. Their values were , PI 52.6 (SD 10.4), PT 13.0 (SD 6.8) and SS 39.6 (SD 7.9). They compared the values between males and females and did not find any significant difference. They did not detect any significant changes in these parameters with aging. This has been shown in many other similar studies which have concluded that the pelvic incidence did not change after adulthood. It is seen that our values of PI , SS ,and LL are comparable to their values, obtained in an asymptomatic cohort of such large numbers.

However, unlike the finding of Macthiong et al (59) , the pelvic incidence and pelvic tilt in our study were significantly different in males and females. The mean PI in males was 48.52 and in females was 53.8 (P = .047). The mean value of PT in male was 11.697, and in females was 15.72 (P = 0.1). The differences in values for PI and PT was found to be significant as evidenced by the t test. This difference could be due to our small sample size not being representative. Our sample size is comparable to the original study by Legaye et al(45) . Legaye et al found the mean PI as 53.2 (SD 10.3), in men and 48.2 (SD 7.0) in women. It can be seen that the mean values in males are lower and females are higher in our study. Whether this is actually due to a difference in the shape of the pelvis in Asian population is to be further studied.

Similar to the study by Hubert Labelle et al (58), we were able to demonstrate significant differences in the values of PI and PT between the spondylolisthesis and control population. The sacral slope and the lumbar lordosis were not significantly different. The mean pelvic incidence in our spondylolisthesis group is 59.31 . In the study by Hubert Labelle it was 71.6. These differences could be due to the less number of patients with high grade spondylolisthesis in our study group.

Like many similar studies done previously, we demonstrated that the pelvic incidence and pelvic tilt correlate positively with the grade of slip. We measured the lumbar index , which is a measure of the anatomic deformation of the fifth lumbar vertebra. Our mean value of 0.793 in spondylolisthesis group was significantly different in the control population (0.921). Saraste et al have described a lumbar index less than 0.75 as having association with high grade spondylolisthesis.

LIMITATIONS OF THIS STUDY

The main limitation to our study is , as mentioned before that the control population is not from asymptomatic subjects. But the parameters of our control group do match the values of asymptomatic control subjects of other studies. Our study is a retrospective study. To demonstrate a high pelvic incidence association with higher grades of spondylolisthesis, a longitudinal study is ideal. The small sample size in our study is another drawback. Most of the similar studies have used dedicated software to measurements from radiograph. Such software was unavailable to us and the measurements were done manually, which could predispose to more error.

CONCLUSIONS

There is a significant difference in the PI between the study and control groups (59.1 vs. 50.7 degrees respectively), indicating that PI may have a contributory effect to the development and/or progression of isthmic spondylolisthesis. The PT was similarly significantly different between the two groups, indicating that spinopelvic alignment may have a causative role in the pathogenesis of this condition. Subgroup analysis showed that there is a trend of increasing PI and PT with increasing grade of spondylolisthesis.

Sacral slope (SS) and lumbar lordosis (LL) were not significantly different between the two groups.

The difference in lumbar index (LI) between the two groups (79% in the study group vs. 92% in the control group) may indicate a causative role of the trapezoidal shaped L5 vertebral body in the progression of adult isthmic spondylolisthesis.

There may be significant gender differences difference between the pelvic incidence (PI) values in the control population. Our study showed a mean PI in males of 48.52 and in females was 53.8 (P = .047). This result has not been seen in other studies. This may be due to the small sample size in our study or possible due to the anthropometric differences in the Asian population. Further research is needed to clarify this finding.

Bibliography

1. Herbiniaux, M. G. Traite sur divers accouchements laborieux et sur les polypes de la matrice. Bruxelles, V. I, pp. 349-3 54,1782.

2. Kilian, H. Fr. De spondylolisthesi gravissimıe pelvangustiaı caussa nuper detecta. Bonnaı., 1854. 34 pp.

3. Junghanns, H. : Spondylolisthese. Beitr. z. Kim. Chir., 148: 554-573, 1930.

4. Grays anatomy 40th edition churchil livingstone 2008.

5. Inderbir singh,G P pal Human embryology, Mc Millan India 2007.

6. Fredrickson BE, Baker D, McHolick WJ, et al. The natural history of spondylolysis and spondylolisthesis. J Bone Joint Surg [Am] 1984;66:699–707.

7. Labelle H, Roussouly P, Berthonnaud E et al (2005) The importance of spinopelvic balance in L5-S1 developmental spondylolisthesis: a review of pertinent radiologic measurements. Spine 30(suppl):27–34.

8. Wiltse et al. Spondylolisthesis: classification and aetiology. Symposium on the Spine. Chicago: American Academy of Orthopedic Surgeons, 1969:143– 166.

9. Lily M. Belfi, MD, A. Orlando Ortiz, MD, MBA, and Douglas S. Katz, MD Computed Tomography Evaluation of Spondylolysis and Spondylolisthesis in Asymptomatic Patients SPINE Volume 31, Number 24, pp E907–E910.

10. Wiltse, L. L.: The Etiology of Spondylolisthesis. J. Bone and Joint Surg., 44-A: 539-560, April 1962-560,.

11. Laurent L, Einola S. Spondylolisthesis in children and adolescents. Acta Orthop Scand 1961;31:45–64.

12. Borkow SE, Kleiger B. Spondylolisthesis in the newborn: A case report. Clin Orthop 1971;81:73–6.

13. Rebecca L. Carl, MD, Kenneth J. Noonan, MD, and Blaise A. Nemeth, MD Isthmic Spondylolisthesis in a Nonambulatory Patient A Case Report SPINE Volume 32, Number 24, pp E723–E724.

14. Floman Y. Progression of lumbosacral isthmic spondylolisthesis in adults. Spine 2000;25:342–7.

15. Seitsalo S, Osterman K, Hyvarinen H, et al. Progression of spondylolisthesis in children and adolescents: a long-term follow-up of 272 patients. Spine 1991;16:417–21.

16. Simper LB. Spondylolysis in Eskimo skeletons. Acta Orthop Scand 1986;57:78–80.

17. Ogilvie JW, Sherman J. Spondylolysis in Scheuermann's disease. Spine 1987;12:251–3.

18. Dandy DJ, Shannon MJ. Lumbo-sacral subluxation. (Group 1 spondylolisthesis).J Bone Joint Surg [Br] 1971;53:578–95.

19. Wiltse LL, Newman PH, Macnab I. Classification of spondylolysis and spondylolisthesis. Clin Orthop 1976;117:23–9.

20. Marchetti PG, Bartolozzi P. Classification of spondylolisthesis as a guideline for treatment. In: The Textbook for Spinal Surgery. Vol. 2. Philadelphia, PA: Lippincott Raven, 1997; 1211–54.

21. Rowe, G.G., and Roche, M.B. : The Etiology of Separate NeuralArch. J. Bone and Joint Surg.,35-A: 102-111, Jan. 1953.

22. Roderts , R.A. : Chronic Structural LowBack Ache Due to Low Back Structural Derangements. London, H.K. Lewis, 1947.

23. Depalma A.F., and Marone PJ, Spondylolysis Following Spinal Fusion. Clin. Orthop., 15: 208-21 1, 1959.

24. Stewart, T.D. : Examination of the Possibility that Certain Skeletal Characters Predispose to Defects in the Lumbar Neural Arches. Clin. Orthop., 8: 44-60, 1956.

25. Nathan Hilel: Spondylolysis. Its Anatomy and Mechanism of Development. J. Bone and Joint Surg., 41-A: 303-319, March 1959.

26. Roussouly P, Gollogly S, Berthonnaud E, et al. Sagittal alignment of the spine and pelvis in the presence of L5–S1 isthmic lysis and lowgrade spondylolisthesis. Spine 2006;31:2484–90.

27. Ying Li, MD M. Timothy Hresko, MD Radiographic Analysis of Spondylolisthesis and Sagittal Spinopelvic Deformity J Am Acad Orthop Surg 2012;20: 194-205.

28. Newman P.H. : Spondylolisthesis. Its Cause and Effect. Ann. Roy. Coil. Surg., England, 16:305-322, 1954-1955.

29. Neugebaiter, Franz: I)ie Entstehung der Spondylolisthesis. Centr:Llab f. Gynak., 5: 260-261, 1881.

30. Savarirayan R, White SM, Goodman FR, et al. Broad phenotypic spectrum caused by an identical heterozygous CDMP-1 Mutation in three unrelated families. Am J Med Genet A 2003;117A:136–42.

31. Lieven Moke, MD, Philippe Debeer, MD, PhD, and Pierre Moens, MD Spondylolisthesis in Twins: Multifactorial Etiology A Case Report and Review of the Literature SPINE Volume 36, Number 11, pp E741–E746.

32. Bosworth, D.M; Fielding, W.;Demarest,Lawrence; and Bonoquist, Mario: Spondylolisthesis. A Critical Review of a Consecutive Series Treated by Arthrodesis. J. Bone and Joint. Surg., 37-A: 767-786, July 1955.

33. Martin J. Herman, MD; and Peter D. Pizzutillo, MD Spondylolysis and Spondylolisthesis in the Child and Adolescent A New ClassificationCLINICAL ORTHOPAEDICS AND RELATED RESEARCH Number 434, pp. 46–54.

34. King HA. Back pain in children. Orthop Clin North Amer. 1999;30(3):467-474.

35. Albanese M, Pizzutillo PD. Family study of spondylolysis and spondylolisthesis. J Pediatr Orthop 1982;2:496–9.

36. Jean-Marc Mac-Thiong , MD , PhD , Luc Duong , PhD , Stefan Parent , MD, PhD , Michael Timothy Hresko , MD , John R. Dimar , MD , Mark Weidenbaum , MD ,and Hubert Labelle , MD Reliability of the Spinal Deformity Study Group Classifi cation of Lumbosacral Spondylolisthesis SPINE Volume 37, Number 2, pp E95–E102.

37. Michael T. Hresko, MD, Hubert Labelle, MD,Pierre Roussouly, MD, and Eric Berthonnaud, PhDClassification of High-Grade Spondylolistheses Based on Pelvic Version and Spine Balance SPINE Volume 32, Number 20, pp 2208–2213.

38. Saraste H. Long-term clinical, radiological follow-up of spondylolysis, spondylolisthesis. J Pediatr Orthop 1987;7:631–8.

39. Thomas R. Jones, MD, PhD Raj D. Rao, MD Adult Isthmic Spondylolisthesis J Am Acad Orthop Surg 2009;17: 609-617.

40. Milard L"The Scotty dog and his collar".. J Ark Med Soc. 1976 Jan;72(8):339-40.

41. Hensinger RN. Spondylolysis and spondylolisthesis in children and adolescents. J Bone Joint Surg Am 1989;71:1098–107.

42. Meyerding, H. W.: Spondylolisthesis. Surg., Gynec., And Obstet., 54: 371-377, 1932.

43. Etienne Bourassa-Moreau, BSc, Jean-Marc Mac-Thiong, MD, PhD, and Hubert Labelle, MDRedefining the Technique for the Radiologic Measurement of Slip in Spondylolisthesis SPINE Volume 35, Number 14, pp 1401–1405.

44. Dubousset J: Treatment of spondylolysis and spondylolisthesis in children and adolescents. Clin Orthop Relat Res 1997;(337):77-85.

45. Legaye J, Duval-Beaupe`re G, Hecquet J, et al. Pelvic incidence: a fundamental pelvic parameter for 3D regulation of spinal sagittal curves. Eur Spine J 1998;7:99–103.

46. Roussouly P, Gollogly S, Berthonnaud E, Dimnet JClassification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. .Spine (Phila Pa 1976). 2005 Feb 1;30(3):346-53.

47. Stagnara P, De Mauroy JC, Dran G, Gonon GP, Costanzo G, Dimnet J, Pasquet A Reciprocal angulation of vertebral bodies in a sagittal plane: approach to references for the evaluation of kyphosis and lordosis.. Spine (Phila Pa 1976). 1982 Jul-Aug;7(4):335-42.

48. Legaye J: Influence of the sagittal balance of the spine on the anterior pelvic plane and on the acetabular orientation. Int Orthop 2009;33(6):1695-1700.

49. Hubert Labelle , Pierre Roussouly , Daniel Chopin , Eric Berthonnaud, Timothy Hresko, Mike O'Brien Spino-pelvic alignment after surgical correction for developmental spondylolisthesis Eur Spine J (2008) 17:1170–1176.

50. Taillard WF: Etiology of spondylolisthesis. Clin Orthop Relat Res 1976; (117):30-39.

51. Lukasz J. Curylo, MD, Charles Edwards, MD, and Ronald W. DeWald, MD. Radiographic Markers in Spondyloptosis Implications for Spondylolisthesis Progression.SPINE Volume 27, Number 18, pp 2021–2025.

52. Darrell S. Hanson, MD, Keith H. Bridwell, MD, John M. Rhee, MD,and Lawrence G. Lenke, MD Correlation of Pelvic Incidence With Low- and High-Grade Isthmic Spondylolisthesis SPINE Volume 27, Number 18, pp 2026–2029.

53. Raphae¨l Vialle, Brice Ilharreborde , Cyril Dauzac,Thibault Lenoir, Ludovic Rillardon, Pierre Guigui ,Is there a sagittal imbalance of the spine in isthmic spondylolisthesis? A correlation study Eur Spine J (2007) 16:1641–1649.

54. J. C. Le Huec , S. Aunoble , Leijssen Philippe Pellet Nicolas ,Pelvic parameters: origin and significanceEur Spine J (2011) 20 (Suppl 5):S564–S571.

55. Péter Rajnics, Alexandre Templier, Wafa Skalli, Francois Lavaste, and Tamás Illés ,The Association of Sagittal Spinal and Pelvic Parameters in Asymptomatic Persons and Patients with Isthmic SpondylolisthesisJournal of Spinal Disorders & Techniques Vol. 15, No. 1, pp. 24–30.

56. C. Marty B. Boisaubert H. Descamps J. P. Montigny J. Hecquet J. Legaye G. Duval-Beaupère The sagittal anatomy of the sacrum among young adults, infants, and spondylolisthesis patientsEur Spine J (2002) 11 :119–125.

57. Jackson RP, Phipps T, Hales C, Surber J: Pelvic lordosis and alignment in spondylolisthesis. Spine (Phila Pa 1976) 2003;28(2):151-160.

58. Labelle H, Roussouly P, Berthonnaud E, Transfeldt E, O'Brien M, Hresko T, Chopin D, Dimnet J Spondylolisthesis, pelvic incidence and sagittal spino-pelvic balance: a correlation study. Spine 2004 29(18):2049–2054.

59. Jean-Marc Mac-Thiong , P. Roussouly , E´. Berthonnaud , P. Guigui Age- and sex-related variations in sagittal sacropelvic morphology and balance in asymptomatic adults Eur Spine J (2011) 20 (Suppl 5):S572–S577.

Data sheet: Control group

S No.	Age	Sex	Diagnosis	Pelvic incidence	Sacral Slope	Pelvic Tilt	Lumbar Lordosis	Lumbar index
1	25	M	Mechanical LBA	47*	45*	2*	58.25*	0.99
2	26	F	Mechanical LBA	53.2*	40*	13.2*	50.7*	0.94
3	24	M	Mechanical LBA	43*	40*	13*	57.7*	0.88
4	27	M	Mechanical LBA	37*	32*	5*	60*	0.93
5	39	M	Mechanical LBA	50*	48*	2*	65.36*	0.93
6	39	F	Mechanical LBA	38.84*	33.65*	5.19*	60.62*	0.84
7	38	F	Mechanical LBA	46.94*	34*	12.94*	50.31*	0.97
8	36	M	Mechanical LBA	48.46*	39.43*	9.03*	49.94*	0.98
9	35	M	Mechanical LBA	46.96*	40.12*	6.84*	59.43*	0.9
10	36	M	Mechanical LBA	40.23*	35*	5.23*	46*	0.99
11	27	M	Mechanical LBA	70*	37*	33*	33*	0.96
12	26	M	Mechanical LBA	43.75*	40.4*	3.35*	60*	0.94
13	30	M	Mechanical LBA	41.6*	35*	6.6*	51.28*	0.98
14	33	F	Mechanical LBA	53.89*	34.4*	19.49*	53.94*	0.83
15	33	M	Mechanical LBA	39.36*	30*	9.36*	45.3*	0.97
16	37	F	Mechanical LBA	56.44*	50.37*	6.04*	74.2*	0.89
17	25	M	Mechanical LBA	35*	28*	7*	46.76*	0.93
18	22	M	Mechanical LBA	55.83*	45*	10.83*	53.18*	0.8
19	26	M	Mechanical LBA	38.91*	19.57*	19.34*	29.13*	0.85
20	28	M	Mechanical LBA	60.5*	50*	10.5*	70.76*	0.88
21	29	F	Mechanical LBA	57.16*	46.4*	10.76*	52.2*	0.91
22	30	F	Mechanical LBA	67.58*	30.27*	37.31*	50.77*	0.87
23	31	M	Mechanical LBA	33.39*	30.14*	3.25*	52.1*	0.93
24	24	F	Mechanical LBA	57.73*	48*	9.73*	62.14*	0.81
25	36	M	Mechanical LBA	60*	49*	11*	64*	0.92
26	38	M	Mechanical LBA	40*	30*	10*	50*	0.88
27	40	M	Mechanical LBA	53.52*	45*	8.53*	67.3*	0.88
28	40	M	Mechanical LBA	55.35*	33*	22.35*	48.37*	0.99
29	23	F	Mechanical LBA	54*	40*	14*	54.55*	0.89
30	23	M	Mechanical LBA	50*	42*	8*	64.32*	0.965
31	27	F	Mechanical LBA	52.13*	26.67*	25.56*	30.95*	0.9
32	29	M	Mechanical LBA	64.2*	45*	19.2*	58.72*	0.92
33	30	F	Mechanical LBA	54*	33.72*	20.3*	53.3*	0.91
34	21	F	Mechanical LBA	56.21*	39.46*	16.75*	49.82*	0.86
35	22	F	Mechanical LBA	56.2*	45*	11.2*	64.15*	0.82
36	23	M	Mechanical LBA	47.36*	32.21*	15.15*	41.5*	0.85
37	26	M	Mechanical LBA	46.33*	27.33*	19*	34.18*	1.11
38	29	F	Mechanical LBA	56.55*	35*	21.55*	43.5*	1.05
39	31	F	Mechanical LBA	52.3*	26.72*	25.58*	50.8*	0.93
40	32	M	Mechanical LBA	56.72*	41*	15.72*	41.09*	0.95
41	35	F	Mechanical LBA	62.59*	45*	17.59*	48.9*	0.87

42	37	F	Mechanical LBA	39.2*	36.26*	2.94*	45*	1.09
43	24	F	Mechanical LBA	46.3*	31*	15.3*	46*	0.95
44	39	F	Mechanical LBA	60.97*	46*	14.51*	62.06*	0.9
45	40	M	Mechanical LBA	57.19*	28.36*	28.83*	41.53*	0.92

Data sheet : Spondylolisthesis group

S.No	Age	Sex	Diagnosis	Pelvic incidence	Sacral slope	Pelvic tilt	Lumbar Lordosis	lumbar index
1	24	F	Grade 1 L5-S1 listhesis	50.77*	25*	24.3*	63.6*	0.83
2	32	M	Grade 1 L5-S1 listhesis	78*	50*	28*	66.68*	0.88
3	37	F	Grade 1 L5-S1 listhesis	69.44*	35.78*	33.66*	40*	0.7
4	33	M	Grade 1 L5-S1 listhesis	53.19*	51*	2.19*	63.8*	0.9
5	39	M	Grade 2 L5-S1 listhesis	45*	37.67*	7.33*	51.36*	0.83
6	24	M	Grade 1 L5-S1 listhesis	60.78*	31.57*	29.21*	41.86*	0.87
7	38	F	Grade 2 L5-S1 listhesis	57.35*	47.31*	10.04*	61.91*	94
8	31	F	Grade 1 L5-S1 listhesis	30*	30*	0	49*	0.85
9	31	M	Grade 2 L5-S1 listhesis	59.5*	52.5*	7*	85*	0.92
10	25	F	Grade 2 L5-S1 listhesis	66.16*	40.36*	25.79*	53.93*	0.87
11	29	F	Grade 3 L5-S1 listhesis	57.28*	45*	12.28*	58.7*	0.83
12	23	F	Grade 3 L5-S1 listhesis	47.3*	30.63*	16.67*	47*	0.84
13	27	F	Grade 2 L5-S1 listhesis	71*	17*	54*	35*	0.88
14	31	F	Grade 2 L5-S1 listhesis	54.4*	29.3*	25.1*	28.3*	0.8
15	21	F	Grade 3 L5-S1 listhesis	61.6*	33.3*	28.3*	60.8*	0.69
16	37	F	Grade 4 L5-S1 listhesis	63.4*	41*	22.4*	56.43*	0.86
17	34	F	Grade 2 L5-S1 listhesis	49*	30.4*	18.6*	42.23*	0.93
18	36	F	Grade 3 L5-S1 listhesis	60*	48*	12*	58.3*	0.92
19	23	F	Grade 3 L5-S1 listhesis	83.5*	42.5*	41.5*	51.3*	0.6
20	32	F	Grade 3 L5-S1 listhesis	62.9*	45*	17.9*	58.9*	0.66
21	36	F	Grade 1 L5-S1 listhesis	57.3*	19.3*	48*	3.14*	0.84
22	27	M	Grade 1 L5-S1 listhesis	48.72*	34*	14.72*	67*	0.86
23	35	F	Grade 3 L5-S1 listhesis	67.03*	33*	34.03*	38*	0.59
24	35	F	Grade 2 L5-S1 listhesis	45*	35*	10*	59.9*	0.79
25	33	M	Grade 1 L5-S1 listhesis	53.3*	48*	5.3*	59.5*	0.74
26	30	F	Grade 2 L5-S1 listhesis	57.11*	51.77*	5.34*	75*	0.7
27	39	F	Grade 1 L5-S1 listhesis	43*	23.66*	19.34*	32.3*	0.99
28	35	F	Grade 4 L5-S1 listhesis	70*	41.05*	28.95*	52.26*	0.5
29	39	F	Grade 1 L5-S1 listhesis	80.10*	39*	41.10*	52.93*	0.84
30	31	M	Grade 2 L5-S1 listhesis	59.84*	46.4*	13.44*	54.13*	0.7
31	27	M	Grade 1 L5-S1 listhesis	56.67*	54.8*	1.87*	71*	0.72
32	35	F	Grade 2 L5-S1 listhesis	51.53*	38.57*	12.96*	51.46*	0.82
33	23	M	Grade 2 L5-S1 listhesis	95*	54*	41*	53.8*	0.67
34	27	F	Grade 2 L5-S1 listhesis	41*	20*	21*	28*	0.8
35	28	M	Grade 1 L5-S1 listhesis	51*	45*	6*	57*	0.79

36	32	F	Grade 2 L5-S1 listhesis	82*	56*	28*	67*	0.62
37	31	F	Grade 2 L5-S1 listhesis	71.18*	52*	19.8*	80.52*	0.87
38	25	M	Grade 3 L5-S1 listhesis	65*	44*	21*	46*	0.6
39	35	F	Grade 4 L5-S1 listhesis	78.85*	45*	33.85*	55.87*	0.73
40	30	F	Grade 1 L5-S1 listhesis	45*	40*	5*	60*	0.86
41	21	M	Grade 1 L5-S1 listhesis	57*	46*	11*	63.43*	0.83
42	39	M	Grade 1 L5-S1 listhesis	47.46*	36*	11.46*	34.40*	0.83
43	23	M	Grade 2 L5-S1 listhesis	62.43	45	17.43	58.32	0.69
44	28	M	Grade 2 L5-S1 listhesis	52.59*	39*	13.59*	63*	0.84
45	39	F	Grade 1 L5-S1 listhesis	50*	31*	19*	31.42*	0.9

INSTITUTIONAL REVIEW BOARD (IRB)
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VELLORE 632 002, INDIA

Dr.B.J.Prashantham, M.A.,M.A.,Dr.Min(Clinical)
Director, Christian Counseling Centre
Editor, Indian Journal of Psychological Counseling
Chairperson, Ethics Committee, IRB

Dr. Alfred Job Daniel, MS Ortho
Chairperson, Research Committee &
Principal

Dr. Nihal Thomas
MD, MNAMS, DNB(Endo), FRACP(Endo), FRCP(Edin)
Secretary, Ethics Committee, IRB
Additional Vice Principal (Research)

October 22, 2012

Dr. Sanju Daniel
PG Registrar
Department of Orthopedic Surgery.
Christian Medical College
Vellore 632 002

Sub: **FLUID Research grant project NEW PROPOSAL:**
An analysis of the radiological parameters that may influence the development andprogression of adult isthmic spondylolisthesis at L5 – S1 level, with a critical analysis of the role of pelvic incidence.
Dr. Sanju Daniel, PG Registrar, Orthopedic Surgery, Dr. Kenny David, Orthopedic Surgery.

Ref: IRB Min. No.7730 dated 04.01.2012

Dear Dr. Daniel,

The Institutional Review Board (Blue, Research and Ethics Committee) of the Christian Medical College, Vellore, reviewed and discussed your project entitled “An analysis of the radiological parameters that may influence the development and progression of adult isthmic spondylolisthesis at L5 – S1 level, with a critical analysis of the role of pelvic incidence” on January 4, 2012.

The Committees reviewed the following documents:

1. Format for application to IRB submission
2. Cvs of Drs. Sanju Daniel, Kenny David
3. A CD containing documents 1 – 2

The following Institutional Review Board (Ethics Committee) members were present at the meeting held on January 4, 2012 in the CREST/SACN Conference Room, Christian Medical College, Bagayam, Vellore- 632002.

INSTITUTIONAL REVIEW BOARD (IRB)
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Dr. Nihal Thomas
MD, MNAMS, DNB(Endo), FRACP(Endo), FRCP(Edin)
Secretary, Ethics Committee, IRB
Additional Vice Principal (Research)

Name	Qualification	Designation	Other Affiliations
Dr. B.J.Prashantham	MA (Counseling), MA (Theology), Dr Min(Clinical)	Chairperson(IRB)& Director, Christian Counselling Centre	Non-CMC
Mr. Harikrishnan	BL	Lawyer	Non-CMC
Mrs. S. Pattabiraman	BSc, DSSA	Social Worker, Vellore	Non-CMC
Dr. Jayaprakash Muliyil	BSC, MBBS, MD, MPH, DrPH(I DMHC	Academic Officer, CMC	
Mrs. Ellen Ebenezer Benjamin	M.Sc. (Nursing).	Deputy Nursing Superintendent, CMC.	
Dr. Vathsala Sadan	M.Sc. (Nursing), PhD	Addl. Deputy Dean, College Nursing, CMC.	
Dr. Gagandeep Kang	MD, PhD, FRCPath.	Secretary IRB (EC)& Dy. Chairperson (IRB), Professor of Microbiology & Addl. Vice Principal (Research), CMC.	

We approve the project to be conducted as presented.

The Institutional Review Board expects to be informed about the progress of the project, any serious adverse events occurring in the course of the project, any changes in the protocol and the patient information/informed consent and requires a copy of the final report.

Yours sincerely,

Dr. Nihal Thomas
Secretary (Ethics Committee)
Institutional Review Board

Dr Nihal Thomas
MBBS MD MNAMS DNB (Endo) FRACP(Endo) FRCP(Edin)
Secretary (Ethics Committee)
Institutional Review Board

CC: Dr. Kenny David, Professor, Department of Orthopedic Surgery, CMC

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